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Diemer Lopes

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(54) **SYSTEM AND METHOD FOR HEATING WATER**

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F24H 4/04	(2006.01)
F24H 1/20	(2006.01)
F24H 9/12	(2006.01)

(52) **U.S. Cl.**

CPC ***F24H 9/2007*** (2013.01); ***F24H 1/202*** (2013.01); ***F24H 4/04*** (2013.01); ***F24H 9/12*** (2013.01); *F24D 2200/32* (2013.01)

(58) **Field of Classification Search**

CPC F24H 9/2007; F24H 4/04; F24H 1/202; F24H 9/12; F24D 2200/32

See application file for complete search history.

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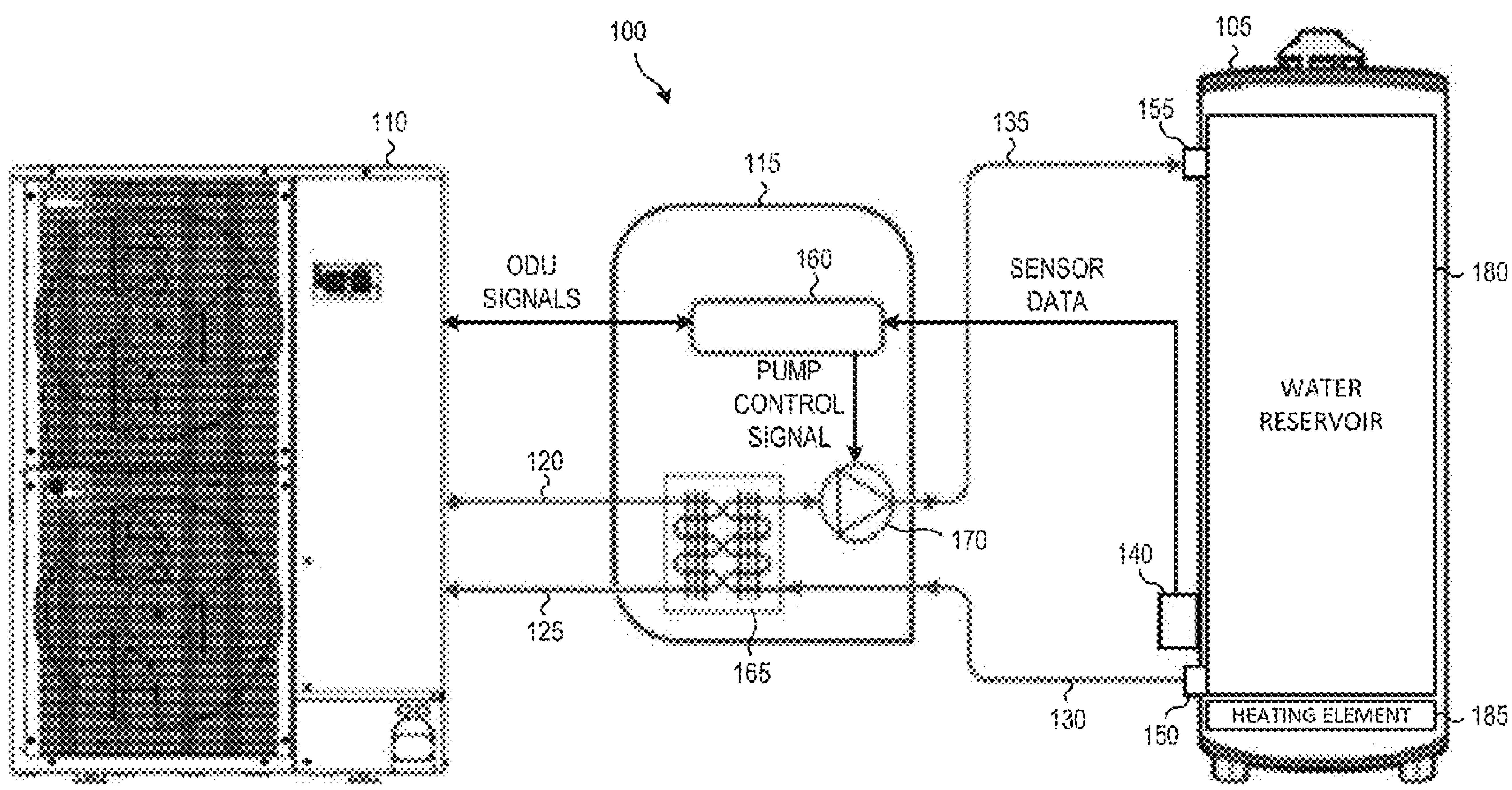
(57) **ABSTRACT**

A water-heating system, including: a controller; a refrigerant-water heat exchanger for exchanging heat between refrigerant and water; a sensor circuit for measuring a current water temperature of water in a water heater and providing the current water temperature to the controller; a first refrigerant pipe for passing the refrigerant from a refrigerant source to the refrigerant-water heat exchanger; a second refrigerant pipe for passing the refrigerant from the refrigerant-water heat exchanger to the refrigerant source; a first water pipe for passing the water from the water heater to the refrigerant-water heat exchanger; a second water pipe for passing the water from the refrigerant-water heat exchanger to the water heater; and a water pump for pumping water from the water heater to the refrigerant-water heat exchanger via the first water pipe and from the refrigerant-water heat exchanger to the water heater via the second water pipe based on a control signal.

21 Claims, 8 Drawing Sheets



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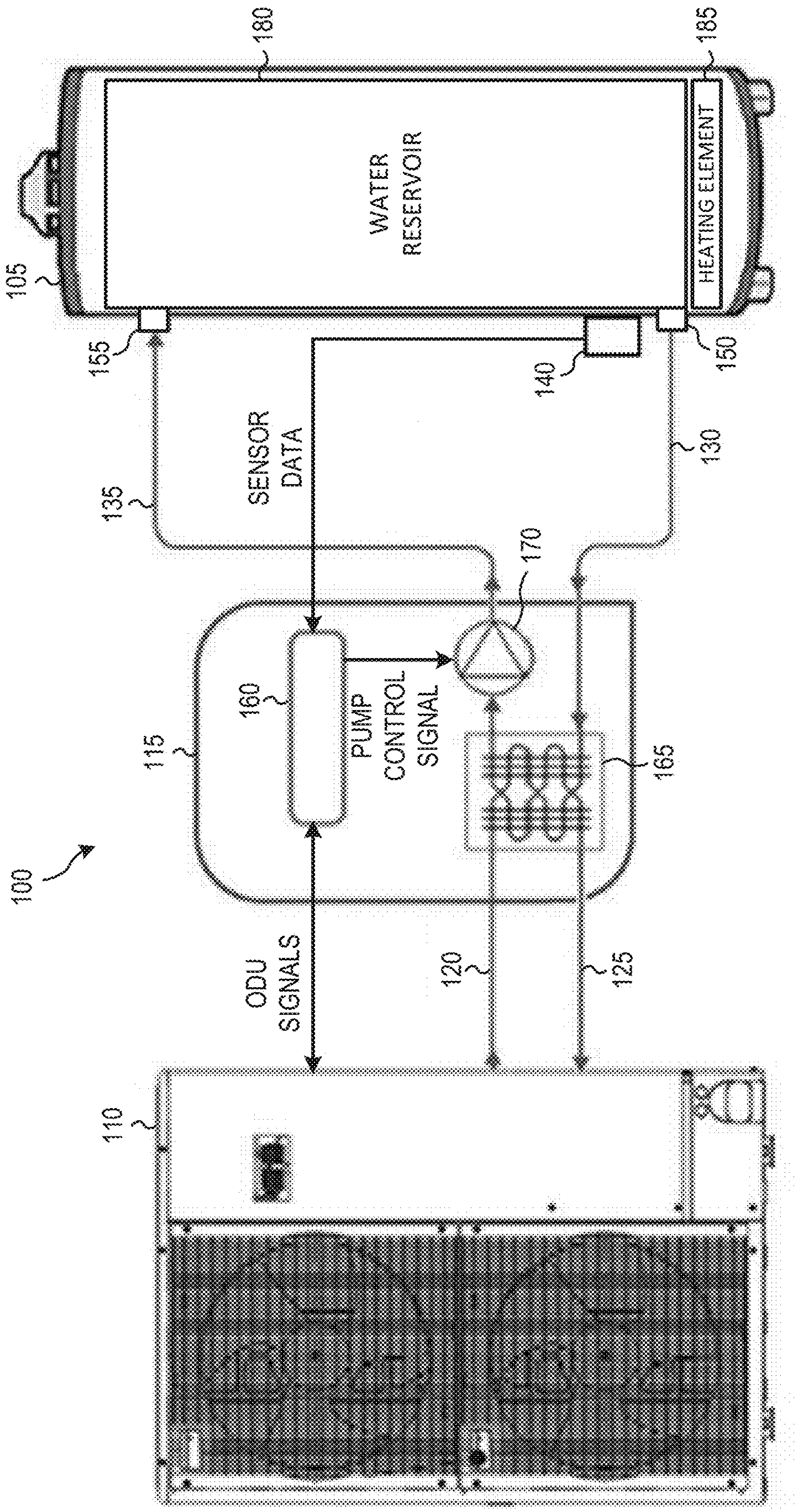
100
105
180
185
WATER RESERVOIR
HEATING ELEMENT
155
140
150
SENSOR DATA
135
130
170
115
160
PUMP CONTROL SIGNAL
165
ODU SIGNALS
120
125
110

FIG. 1

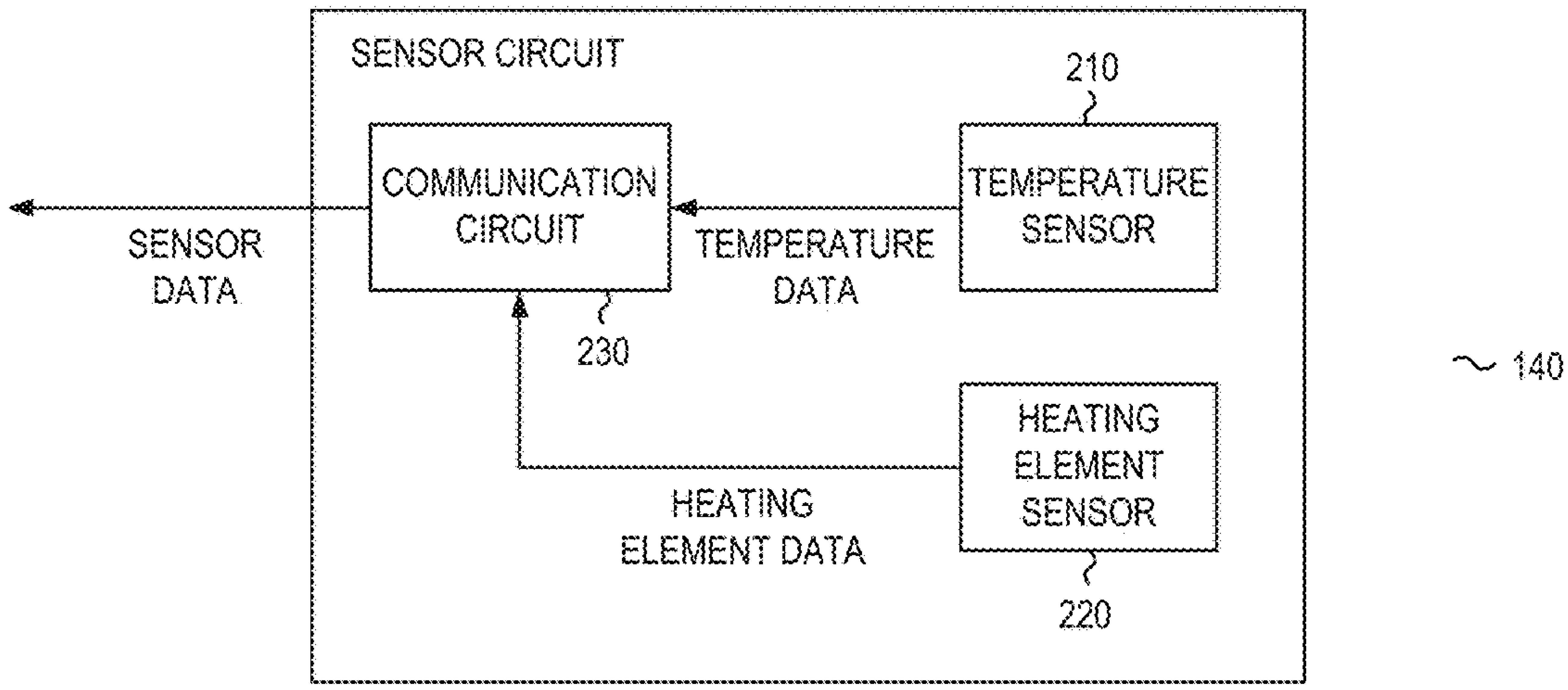
SENSOR CIRCUIT
210
COMMUNICATION CIRCUIT
TEMPERATURE SENSOR
SENSOR DATA
TEMPERATURE DATA
230
140
HEATING ELEMENT SENSOR
HEATING ELEMENT DATA
220

FIG. 2

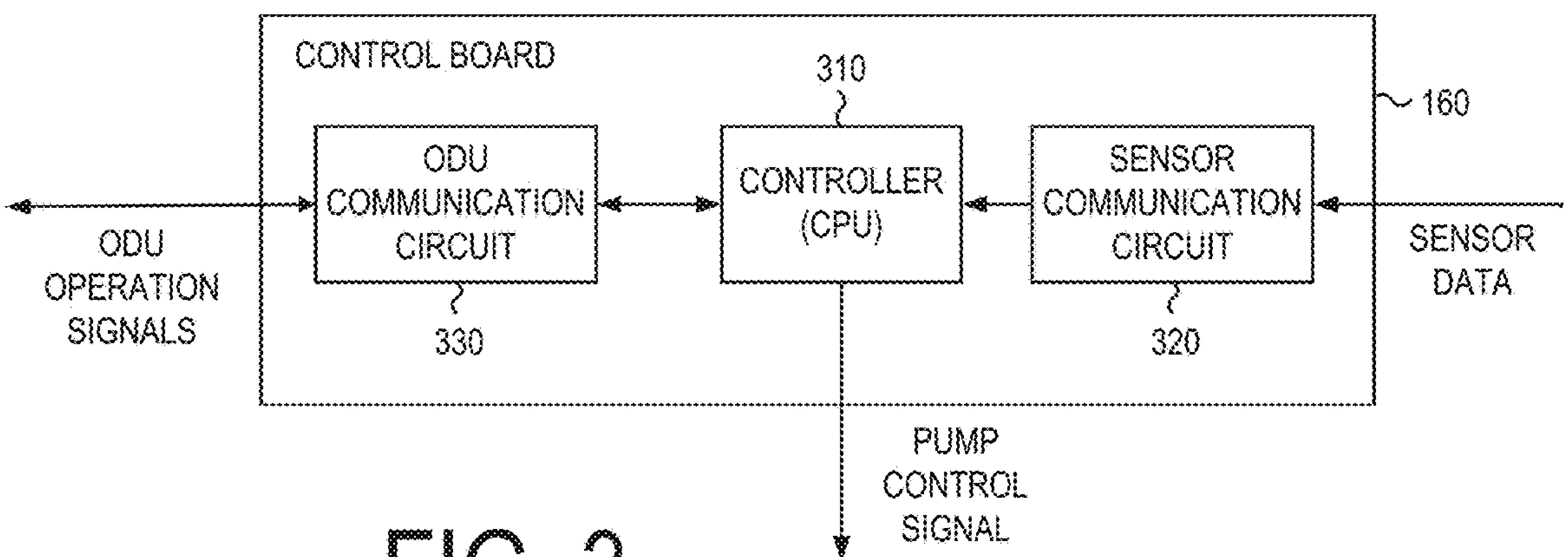
CONTROL BOARD
310
160
ODU COMMUNICATION CIRCUIT
CONTROLLER (CPU)
SENSOR COMMUNICATION CIRCUIT
ODU OPERATION SIGNALS
SENSOR DATA
330
320
PUMP CONTROL SIGNAL

FIG. 3

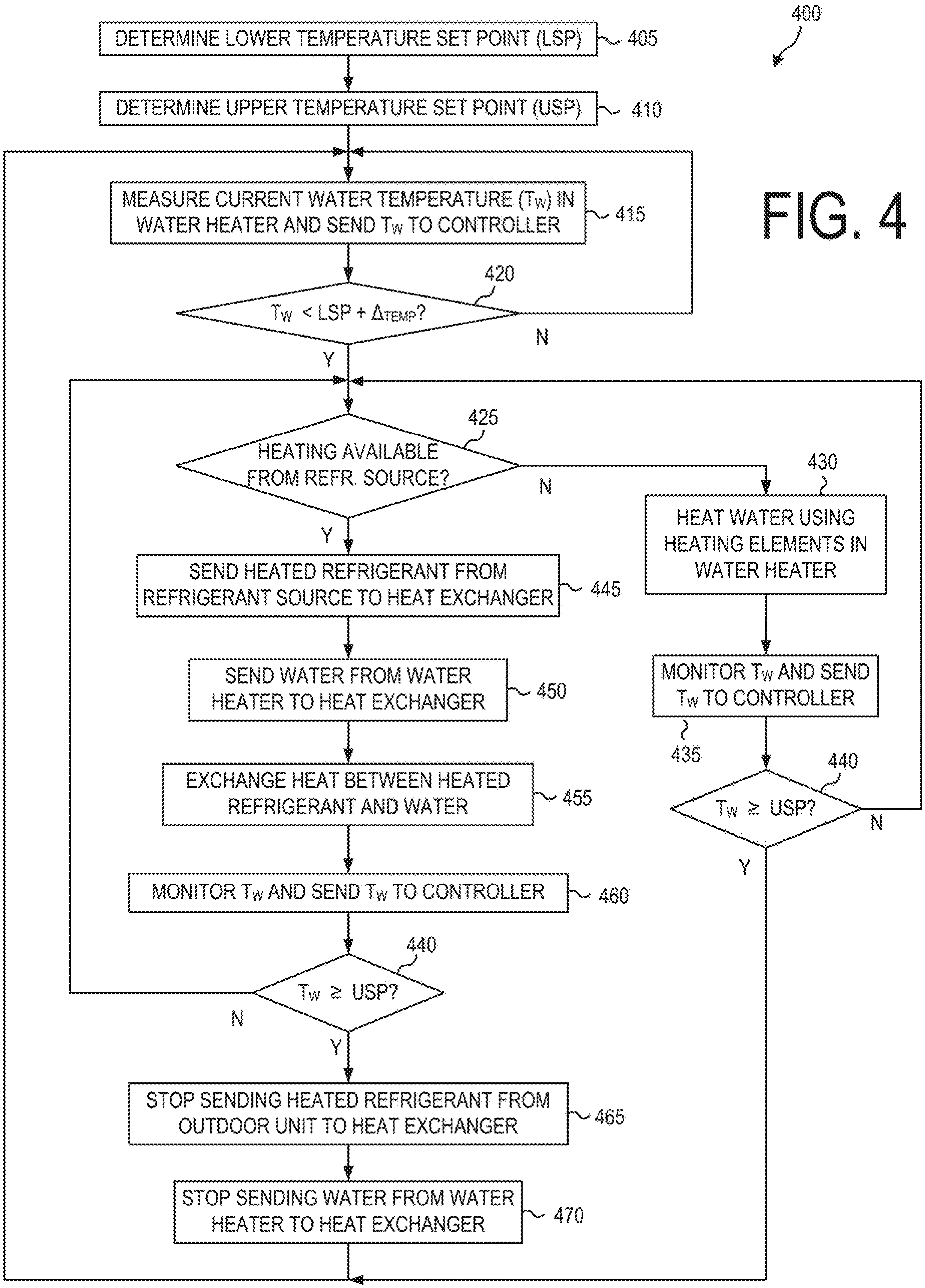
400
DETERMINE LOWER TEMPERATURE SET POINT (LSP)
405
DETERMINE UPPER TEMPERATURE SET POINT (USP)
410
MEASURE CURRENT WATER TEMPERATURE (Tw) IN WATER HEATER AND SEND Tw TO CONTROLLER
415
420
Tw < LSP + ΔTEMP?
N
Y
425
HEATING AVAILABLE FROM REFR. SOURCE?
N
430
HEAT WATER USING HEATING ELEMENTS IN WATER HEATER
Y
SEND HEATED REFRIGERANT FROM REFRIGERANT SOURCE TO HEAT EXCHANGER
445
MONITOR Tw AND SEND Tw TO CONTROLLER
SEND WATER FROM WATER HEATER TO HEAT EXCHANGER
450
435
440
EXCHANGE HEAT BETWEEN HEATED REFRIGERANT AND WATER
455
Tw ≥ USP?
N
Y
MONITOR Tw AND SEND Tw TO CONTROLLER
460
440
Tw ≥ USP?
N
Y
STOP SENDING HEATED REFRIGERANT FROM OUTDOOR UNIT TO HEAT EXCHANGER
465
STOP SENDING WATER FROM WATER HEATER TO HEAT EXCHANGER
470

FIG. 4

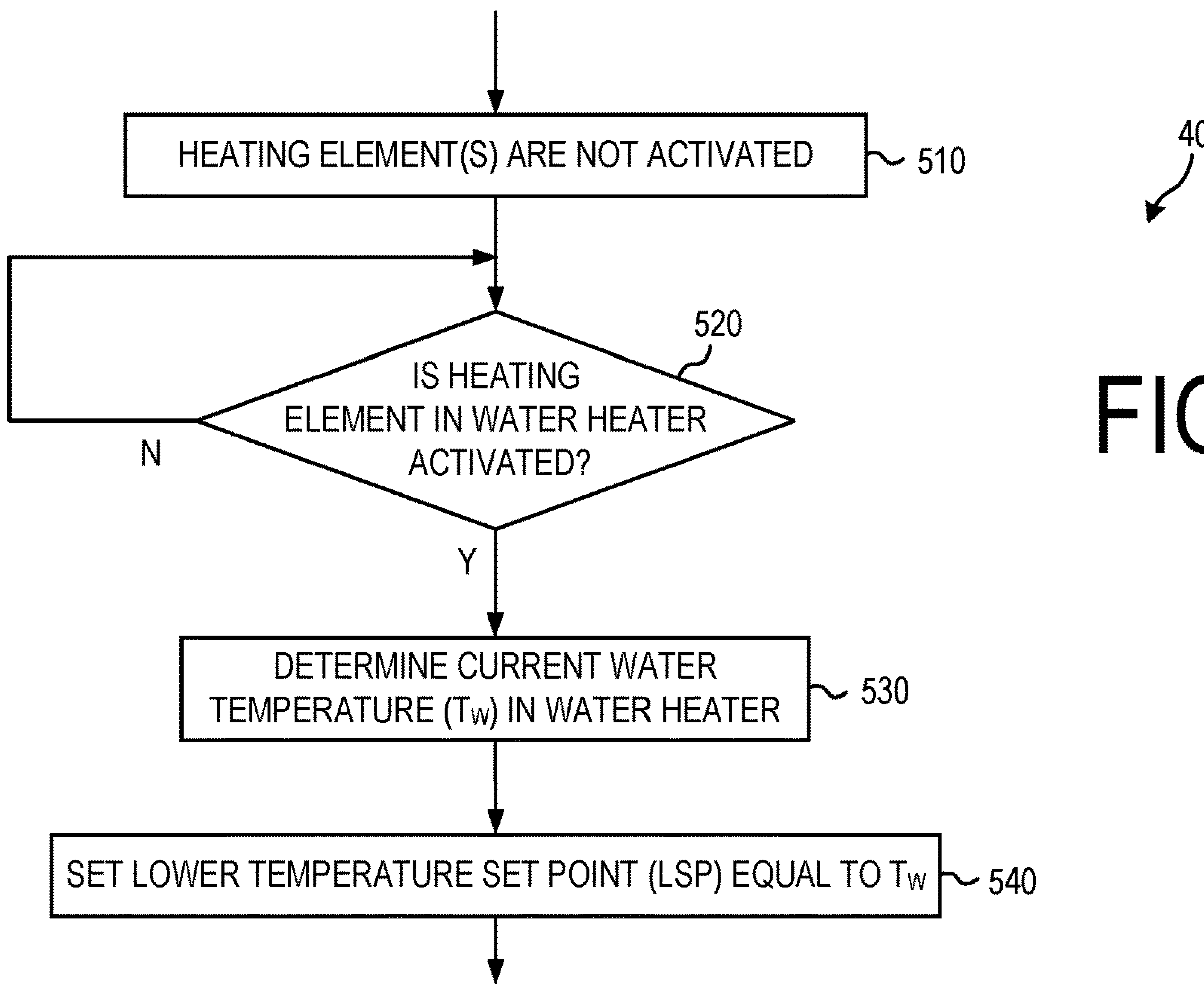
HEATING ELEMENT(S) ARE NOT ACTIVATED
510
405
IS HEATING ELEMENT IN WATER HEATER ACTIVATED?
520
N
Y
DETERMINE CURRENT WATER TEMPERATURE (TW) IN WATER HEATER
530
SET LOWER TEMPERATURE SET POINT (LSP) EQUAL TO TW
540

FIG. 5

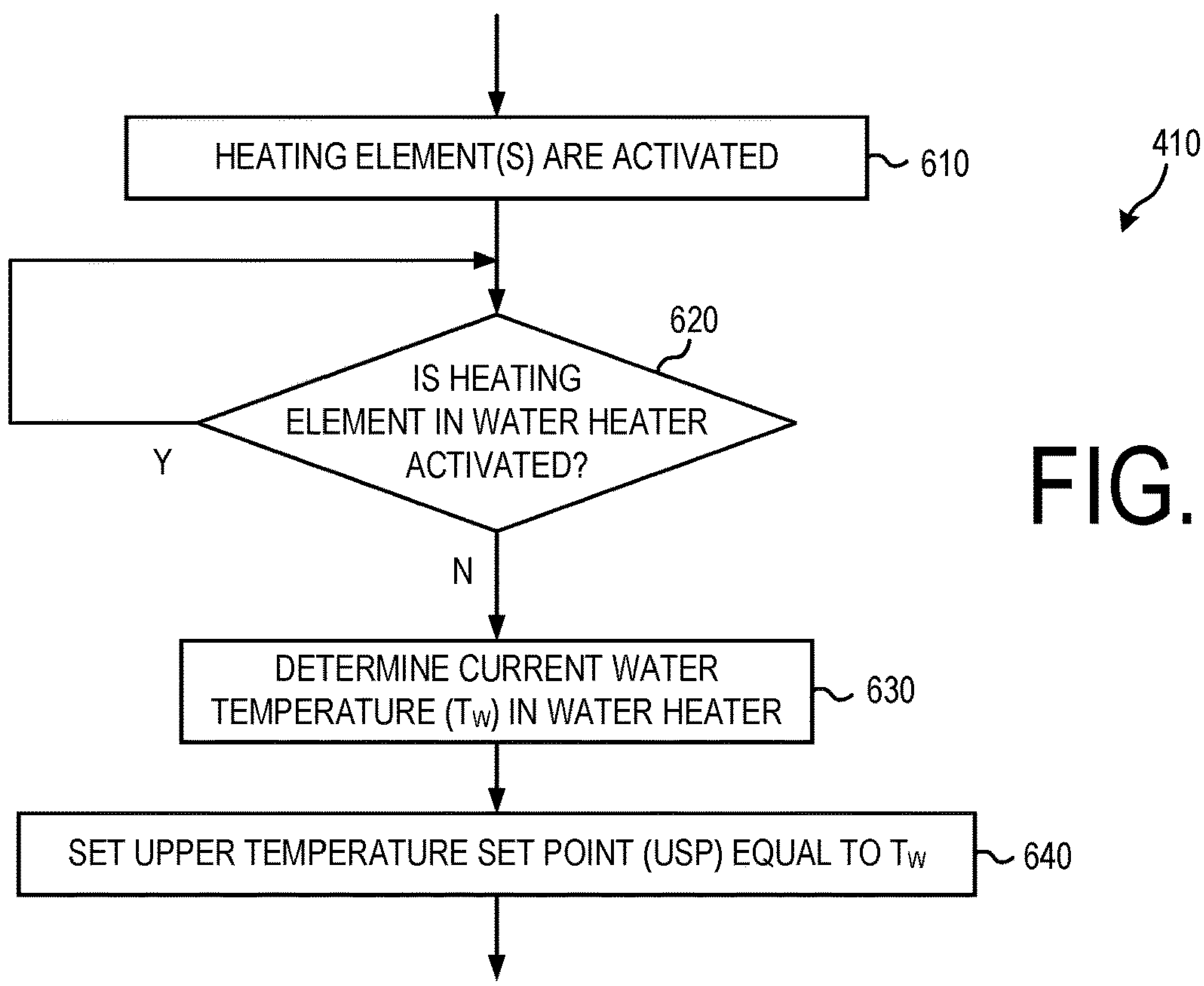
HEATING ELEMENT(S) ARE ACTIVATED
610
410
IS HEATING ELEMENT IN WATER HEATER ACTIVATED?
620
Y
N
DETERMINE CURRENT WATER TEMPERATURE (TW) IN WATER HEATER
630
SET UPPER TEMPERATURE SET POINT (USP) EQUAL TO TW
640

FIG. 6

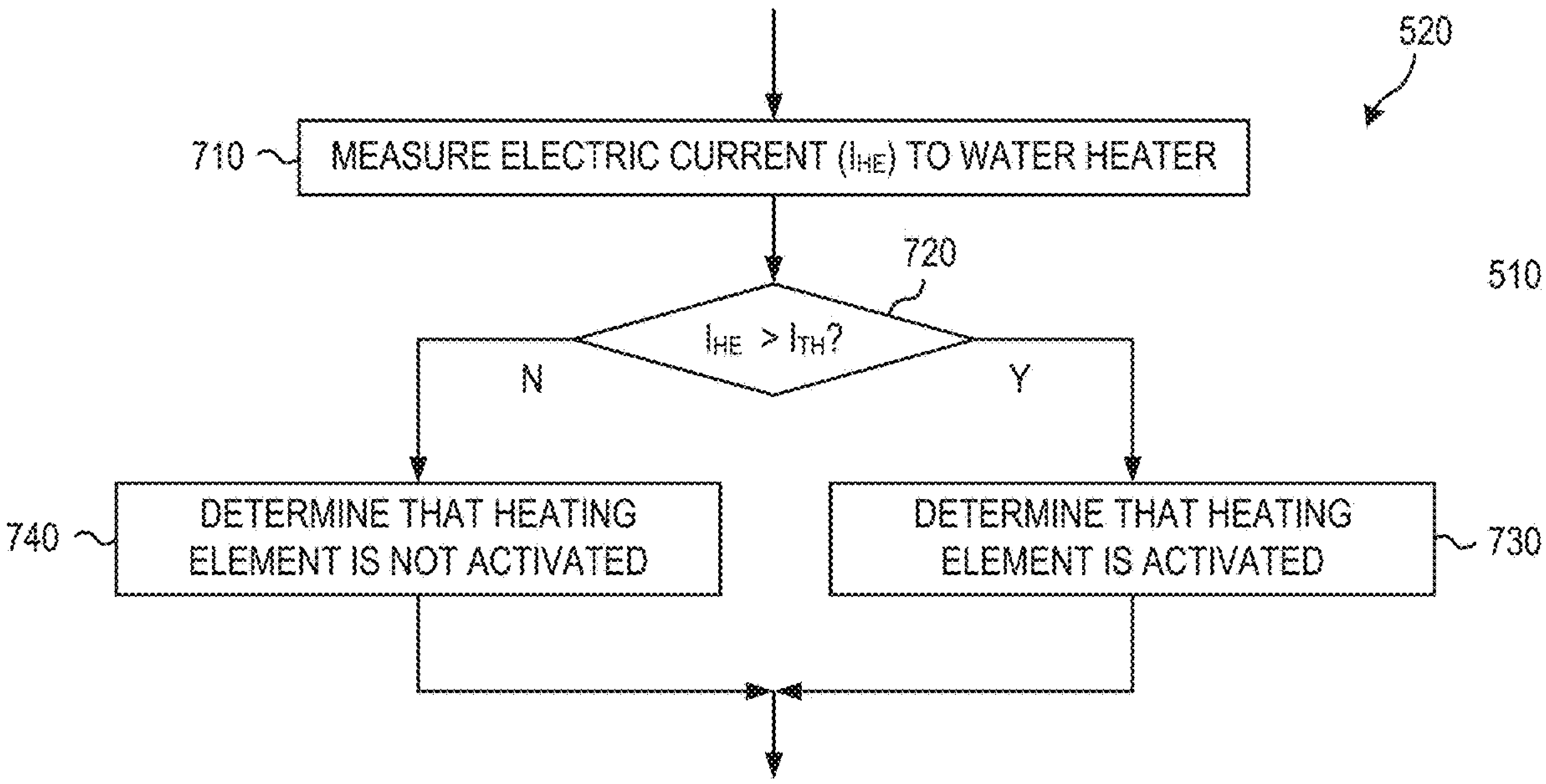
520
510
710
MEASURE ELECTRIC CURRENT (IHE) TO WATER HEATER
720
IHE > ITH?
N
Y
740
DETERMINE THAT HEATING ELEMENT IS NOT ACTIVATED
730
DETERMINE THAT HEATING ELEMENT IS ACTIVATED

FIG. 7

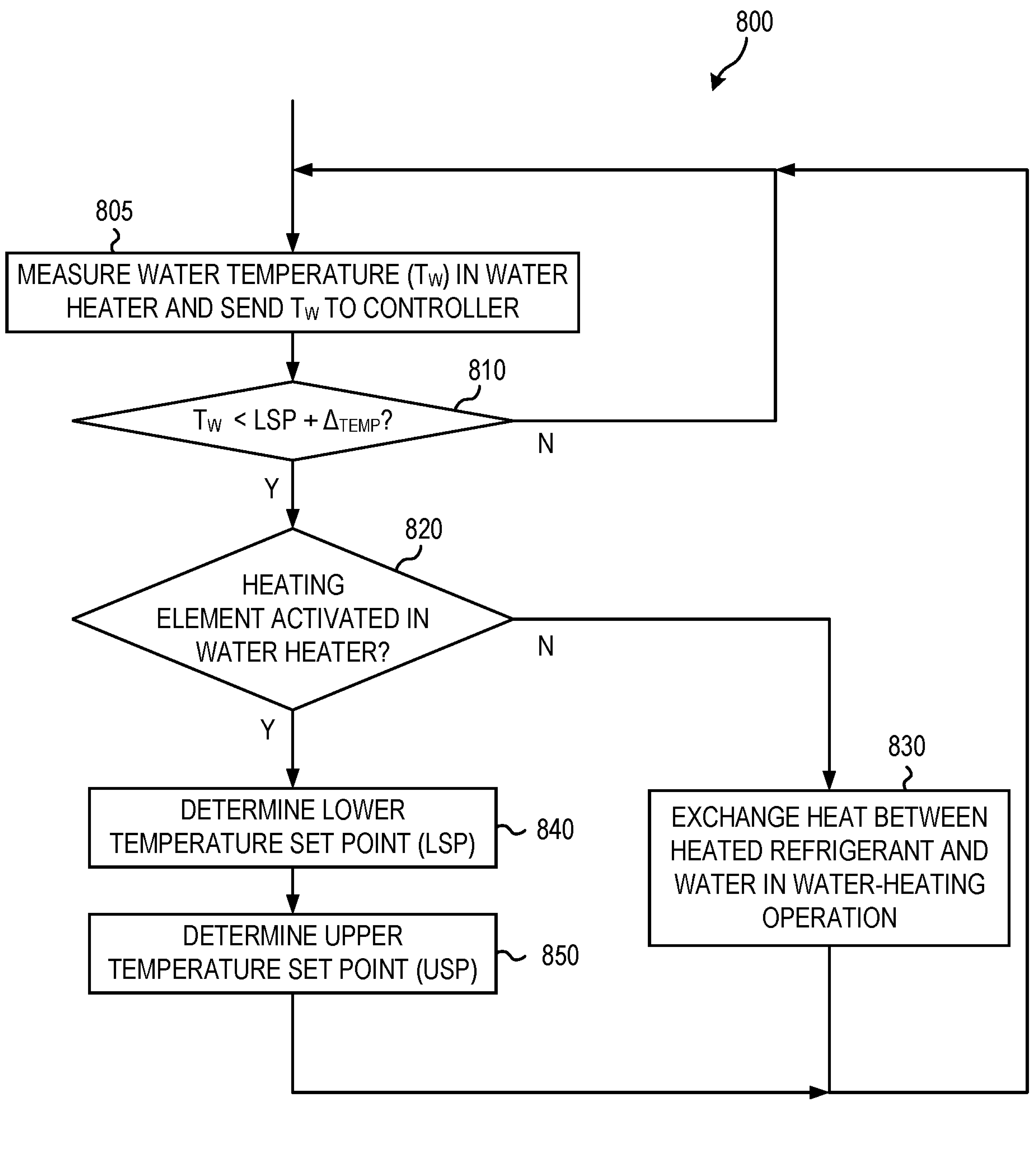
800
805
MEASURE WATER TEMPERATURE (T_W) IN WATER HEATER AND SEND T_W TO CONTROLLER
810
T_W < LSP + Δ_{TEMP}?
N
Y
820
HEATING ELEMENT ACTIVATED IN WATER HEATER?
N
Y
830
EXCHANGE HEAT BETWEEN HEATED REFRIGERANT AND WATER IN WATER-HEATING OPERATION
DETERMINE LOWER TEMPERATURE SET POINT (LSP)
840
DETERMINE UPPER TEMPERATURE SET POINT (USP)
850

FIG. 8

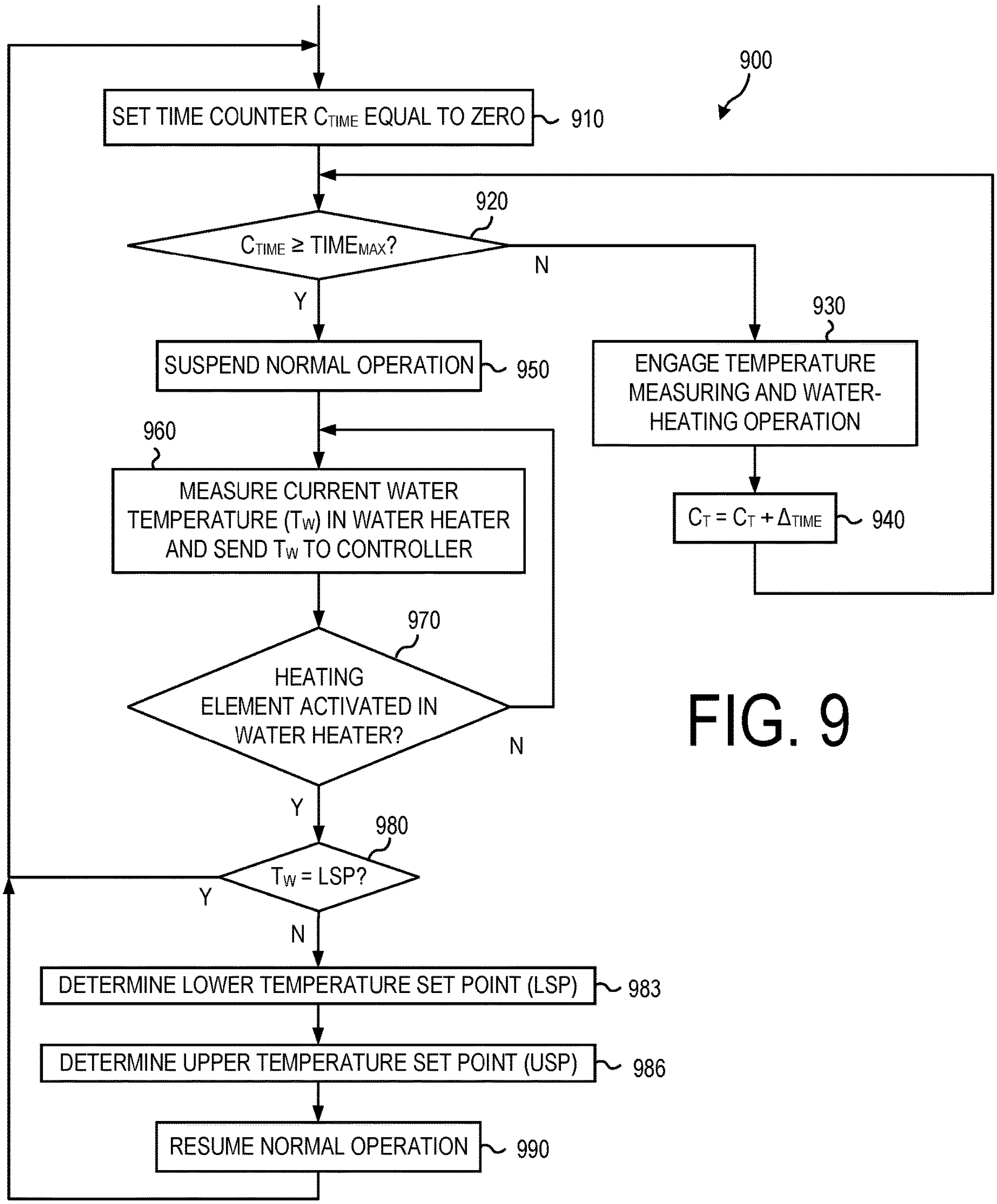
900
SET TIME COUNTER CTIME EQUAL TO ZERO
910
920
CTIME ≥ TIMEMAX?
N
Y
930
ENGAGE TEMPERATURE MEASURING AND WATER-HEATING OPERATION
SUSPEND NORMAL OPERATION
950
960
MEASURE CURRENT WATER TEMPERATURE (TW) IN WATER HEATER AND SEND TW TO CONTROLLER
CT = CT + ΔTIME
940
970
HEATING ELEMENT ACTIVATED IN WATER HEATER?
N
Y
980
TW = LSP?
Y
N
DETERMINE LOWER TEMPERATURE SET POINT (LSP)
983
DETERMINE UPPER TEMPERATURE SET POINT (USP)
986
RESUME NORMAL OPERATION
990

FIG. 9

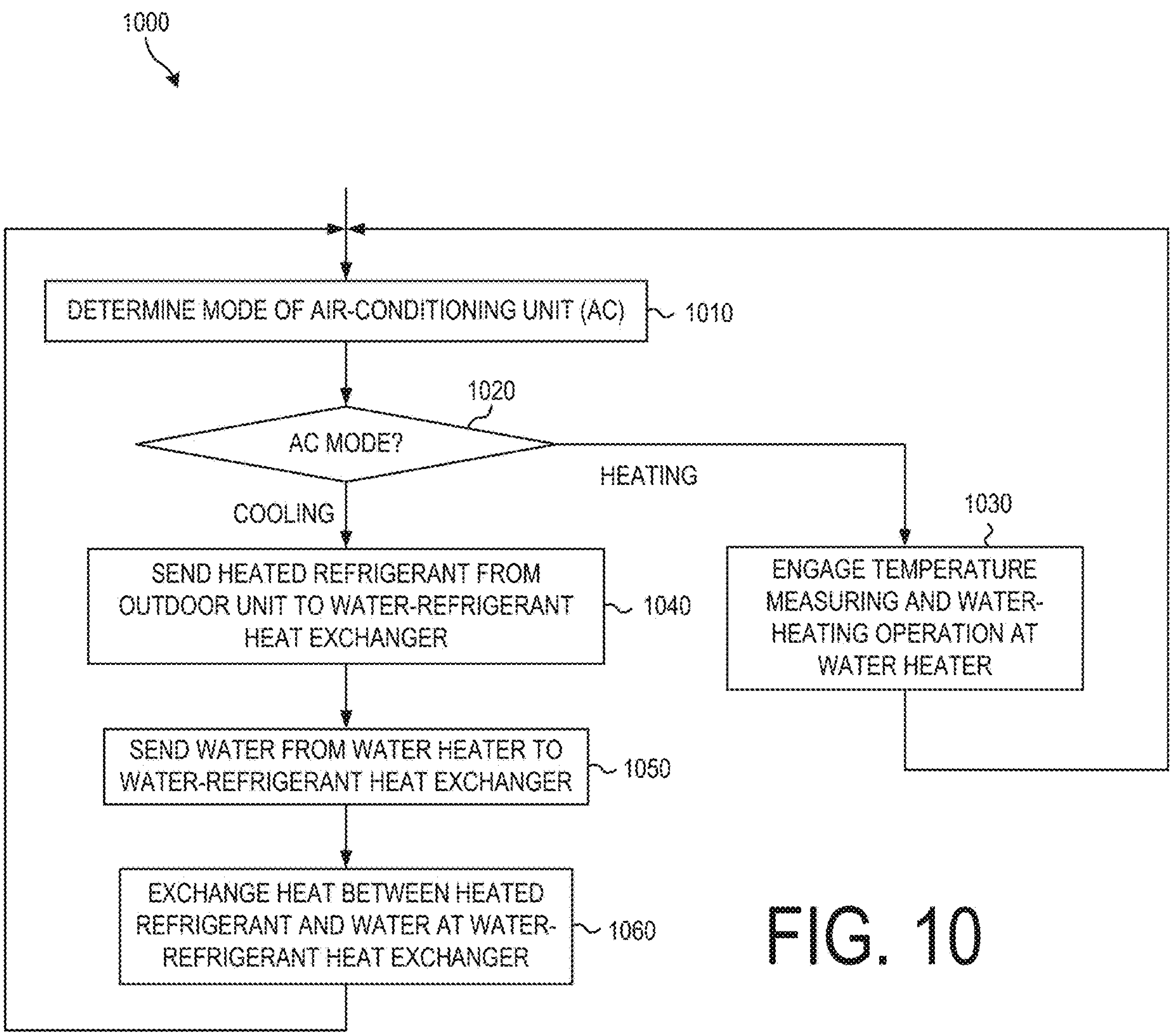
1000
DETERMINE MODE OF AIR-CONDITIONING UNIT (AC)
1010
1020
AC MODE?
HEATING
COOLING
1030
SEND HEATED REFRIGERANT FROM OUTDOOR UNIT TO WATER-REFRIGERANT HEAT EXCHANGER
1040
ENGAGE TEMPERATURE MEASURING AND WATER-HEATING OPERATION AT WATER HEATER
SEND WATER FROM WATER HEATER TO WATER-REFRIGERANT HEAT EXCHANGER
1050
EXCHANGE HEAT BETWEEN HEATED REFRIGERANT AND WATER AT WATER-REFRIGERANT HEAT EXCHANGER
1060

FIG. 10

SYSTEM AND METHOD FOR HEATING WATER

FIELD OF THE INVENTION

The present invention relates generally to hot-water-heating systems that are used proximate to other systems that create waste heat (e.g., air-conditioning systems). More particularly, the present invention relates to a hot water heater that can heat water using waste heat from a nearby heat-generating system instead of a heating element in the hot water heater.

BACKGROUND OF THE INVENTION

A conventional water heater includes a water reservoir and a heating element that heats the water in the water reservoir for use in a residential or commercial property. The heating element can be an electric heater, a gas heater, an oil heater, or any suitable kind of heating element. Regardless of its type, using the heating element to heat the water in the water reservoir consumes resources, whether those resources are electric power, natural gas, oil, coal, etc.

A water heater will typically maintain the water in its water reservoir at a set minimum temperature. To accomplish this, the heating element heats the water whenever it falls below the minimum temperature. This requires periodic operation of the heating element, which consumes the resources (electric power, natural gas, oil, coal, etc.) in proportion to the amount of time that the electric heater operates.

In addition to water heaters, many buildings include systems that generate waste heat. For example, many conventional air-conditioning systems use a heat pump to provide heating during colder temperatures and cooling during warmer temperatures. The heat pump is typically located in an outdoor unit in the air-conditioning system and either heats a refrigerant to warm the air inside a building (in a heating operation) or chills the refrigerant to cool the air inside the building (in a cooling operation).

During the heating operation, the heat pump must continually absorb heat from a heat source (e.g., outside air proximate to the heat pump) to warm the refrigerant so that it can be used to warm the air inside the building. However, during a cooling operation, the heat pump must dissipate heat from the refrigerant (e.g., to outside air proximate to the heat pump) to chill it so that the refrigerant can be used to cool the air inside the building. Generally, this waste heat generated during a cooling operation is put to no useful purpose.

Although air-conditioning systems are one of the most common sources of waste heat in most buildings, there are numerous other sources of waste heat. For example, waste heat is generated by power plants used to produce electric power (e.g., using coal, oil, natural gas, nuclear, etc.), certain industrial processes such as oil refining, steel making, or glass making, the operation of electronic components such as computers, and other systems. In most cases, this waste heat is dissipated to outside air or a passing water supply to no useful purpose.

It would therefore be desirable to provide a mechanism that will use the waste heat generated by a system associated with a building to a heat the water in a water heater located in that building. This could reduce the consumption of heating resources (electric power, natural gas, oil, coal, etc.) for the water heater and thereby reduce the cost of its operation.

SUMMARY OF THE INVENTION

A water-heating system is provided, comprising: a controller; a refrigerant-water heat exchanger configured to exchange heat between refrigerant and water; a sensor circuit configured to measure a current water temperature of water in a water heater and provide the current water temperature to the controller; a first refrigerant pipe configured to pass the refrigerant from a refrigerant source to the refrigerant-water heat exchanger; a second refrigerant pipe configured to pass the refrigerant from the refrigerant-water heat exchanger to the refrigerant source; a first water pipe configured to pass the water from the water heater to the refrigerant-water heat exchanger; a second water pipe configured to pass the water from the refrigerant-water heat exchanger to the water heater; a water pump configured to pump water from the water heater to the refrigerant-water heat exchanger via the first water pipe and from the refrigerant-water heat exchanger to the water heater via the second water pipe based on a pump control signal from the controller, wherein the first water pipe is connected to a tank drain valve on the water heater, the second water pipe is connected to a pressure relief valve on the water heater, and the controller is configured to identify a lower temperature set point for the water in the water heater at which one or more heating elements in the water heater are set to heat the water, determine when the current water temperature is below a threshold temperature but above the lower temperature set point, instruct the water pump to pump water to the refrigerant-water heat exchanger when the current water temperature is below the threshold temperature but above the lower temperature set point, and instruct the refrigerant source to provide refrigerant to the refrigerant-water heat exchanger when the current water temperature is below the threshold temperature but above the lower temperature set point, and the threshold temperature is a set temperature differential greater than the lower temperature set point

The sensor circuit may be attached to the water heater.

The sensor circuit may be further configured to measure an electric current value of an electric current provided to the water heater and provide the electric current value to the controller, and the controller may be further configured to identify the lower temperature set point to be a first water temperature in the water heater when the electric current value first exceeds a current threshold, identify an upper temperature set point to be a second water temperature in the water heater when the electric current value stops exceeding the current threshold, instruct the water pump to stop pumping water to the refrigerant-water heat exchanger when the water in the water heater rises above the upper temperature set point, and instruct the refrigerant source to stop providing refrigerant to the refrigerant-water heat exchanger when the water in the water heater rises above the upper temperature set point.

One or more heating elements in the water heater may be activated when the electric current value exceeds a current threshold and are deactivated when the electric current is below the current threshold.

The refrigerant source may be an air-conditioner. The controller may be a microprocessor.

A method of heating water contained in a water heater is provided, the method including: determining a lower temperature set point that represents a temperature of water in the water heater below which one or more heating elements in the water heater activate to heat the water in the water heater; measuring a pre-heat-exchange water temperature in the water heater after determining the lower temperature set point; determining that the pre-heat-exchange water temperature is below a threshold water temperature but above the lower temperature set point; sending heated refrigerant from a refrigerant source to a refrigerant-water heat exchanger after determining that the pre-heat-exchange temperature is below the threshold water temperature but above the lower temperature set point; sending water from the water heater to the refrigerant-water heat exchanger after it is determined that the pre-heat-exchange temperature is below the threshold water temperature but above the lower temperature set point; and exchanging heat between the refrigerant and the water from the water heater after sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger and sending water from the water heater to the refrigerant-water heat exchanger, wherein the threshold water temperature is a set temperature differential greater than the lower temperature set point.

The set temperature differential may vary based on a rate of change in water in the water heater.

The method may further comprise: repeatedly measuring the pre-heat-exchange water temperature and determining that the pre-heat-exchange water temperature is above the threshold water temperature prior to determining that the pre-heat-exchange water temperature is below the threshold water temperature but above the lower temperature set point.

The operation of determining the lower temperature set point may include: determining whether a heating element in the water heater has been activated; measuring an activation water temperature in the water heater substantially concurrently with determining that the heating element in the water heater has been activated; and setting the lower temperature set point to be equal to the activation water temperature after it is determined that the heating element in the water heater has been activated.

The operation of determining the lower temperature set point ay include: measuring an electric current provided to the water heater; measuring a calibration water temperature in the water heater substantially concurrently with measuring the electric current; determining that the measured electric current is above a current threshold; and setting the lower temperature set point to be equal to the calibration water temperature after it is determined that the measured electric current is above the current threshold.

The method may further comprise: repeatedly measuring the electric current, measuring the recalibration water temperature, and determining that the measured electric current is below the current threshold prior to determining that the measured electric current is above the current threshold.

The method may further comprise: determining an upper temperature set point that represents a temperature of the water in the water heater above which the one or more heating elements are deactivated; measuring a post-heat-exchange water temperature in the water heater after exchanging heat between the refrigerant and the water from the water heater; determining that the post-heat-exchange water temperature is above the upper temperature set point after remeasuring the post-heat-exchange water temperature; stopping sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger after it is determined that the post-heat-exchange temperature is above the upper temperature set point; and stopping sending water from the water heater to the refrigerant-water heat exchanger after it is determined that the post-heat-exchange temperature is above the upper temperature set point.

The method may further comprise: repeatedly measuring the post-heat-exchange water temperature, and determining that the post-heat-exchange water temperature is below the upper temperature set point prior to determining that the post-heat-exchange water temperature is above the threshold water temperature.

The operation of determining the upper temperature set point may include: exchanging heat between the refrigerant and the water from the water heater in the refrigerant-water heat exchanger; measuring an electric current provided to the water heater after exchanging heat between the refrigerant and the water from the water heater in the refrigerant-water heat exchanger; measuring a calibration water temperature in the water heater substantially concurrently with measuring the electric current; determining that the measured electric current is below a current threshold; and setting the upper temperature set point to be equal to the calibration water temperature after it is determined that the measured electric current is below the current threshold.

The method may further comprise: repeatedly measuring the electric current, measuring the calibration water temperature, and determining that the measured electric current is above the current threshold prior to determining that the measured electric current is below the current threshold.

The method may further comprise: determining that heating is available for water in a water heater from the refrigerant source prior to measuring the pre-heat-exchange water temperature.

The refrigerant source may be an air-conditioner, and the operation of determining that heating is available from the refrigerant source may include identifying an operating mode of the air conditioner, and determining that heating is available from the refrigerant source when the air-conditioner is in a cooling mode.

The method may further comprise: comparing a current timer value to a threshold timer value prior to measuring the current water temperature; determining that the current timer value is greater than or equal to the threshold timer value based on the comparing of the current timer value to the threshold timer value; and redetermining the lower temperature set point when the current timer value is greater than or equal to the threshold timer value prior to measuring the current water temperature.

The operation of redetermining the lower temperature set point may include: measuring a recalibration electric current provided to the water heater; measuring the recalibration water temperature in the water heater substantially concurrently with measuring the recalibration electric current; determining that the recalibration electric current is above the current threshold; and setting the lower temperature set point to be equal to the recalibration water temperature after it is determined that the recalibration electric current is above the current threshold.

The method may further comprise: repeatedly measuring the recalibration electric current, measuring the recalibration water temperature, and determining that the measured electric current is below the current threshold prior to determining that the measured electric current is above the current threshold.

A method of heating water contained in a water heater is provided, the method including: determining that a refrigerant source contains excess heat that can be transferred to water in a water heater; determining a first temperature of the water in the water heater; comparing the first temperature of the water in the water heater to a maximum water temperature for the water heater; determining that the first temperature of the water in the water heater is below the maximum water temperature; sending heated refrigerant from a refrigerant source to a refrigerant-water heat exchanger after determining that the first temperature is below the maximum water temperature; sending water from the water heater to the refrigerant-water heat exchanger after determining that the first temperature is below the maximum water temperature; and exchanging heat between the refrigerant and the water from the water heater after sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger and sending water from the water heater to the refrigerant-water heat exchanger.

The refrigerant source may be an air-conditioner, and the operation of determining that the refrigerant source contains excess heat may include identifying an operating mode of the air conditioner, and determining that the air-conditioner is in a cooling mode.

The method may further comprise: determining a second temperature of the water in the water heater after exchanging heat between the refrigerant and the water; comparing the second temperature of the water in the water heater to the maximum water temperature for the water heater; determining that the second temperature of the water in the water heater is above the maximum water temperature; stopping sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger after determining that the second temperature is above the maximum water temperature; and stopping sending water from the water heater to the refrigerant-water heat exchanger after determining that the second temperature is above the maximum water temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying figures where like reference numerals refer to identical or functionally similar elements and which together with the detailed description below are incorporated in and form part of the specification, serve to further illustrate an exemplary embodiment and to explain various principles and advantages in accordance with the present disclosure.

FIG. **1** is a block diagram of a water-heating system using waste heat according to disclosed embodiments;

FIG. **2** is a block diagram of the sensor circuit of FIG. **1** according to disclosed embodiments;

FIG. **3** is a block diagram of the control board of FIG. **1** according to disclosed embodiments;

FIG. **4** is a flow chart of a water-heating system using waste heat according to disclosed embodiments;

FIG. **5** is a flow chart describing the operation of determining a lower temperature set point in FIG. **4** according to disclosed embodiments;

FIG. **6** is a flow chart describing the operation of determining an upper temperature set point in FIG. **4** according to disclosed embodiments;

FIG. **7** is a flow chart describing the operation of determining whether a heating element in a water heater is activated in FIGS. **5** and **6** according to disclosed embodiments;

FIG. **8** is a flow chart describing an operation of identifying when a low temperature setpoint has risen after being set according to disclosed embodiments;

FIG. **9** is a flow chart describing an operation of periodically reevaluating a low temperature set point and an upper temperature setpoint according to disclosed embodiments; and

FIG. **10** is a flow chart describing an operation of determining whether an outdoor unit of an air-conditioner has heated refrigerant available for heat transfer according to disclosed embodiments

DETAILED DESCRIPTION

The instant disclosure is provided to further explain in an enabling fashion the best modes of performing one or more embodiments of the present invention. The disclosure is further offered to enhance an understanding and appreciation for the inventive principles and advantages thereof, rather than to limit in any manner the invention. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

It is further understood that the use of relational terms such as first and second, and the like, if any, are used solely to distinguish one from another entity, item, or action without necessarily requiring or implying any actual such relationship or order between such entities, items or actions. It is noted that some embodiments may include a plurality of processes or steps, which can be performed in any order, unless expressly and necessarily limited to a particular order; i.e., processes or steps that are not so limited may be performed in any order.

Water-Heating System Using Waste Heat

FIG. **1** is a block diagram of a water-heating system **100** using waste heat according to disclosed embodiments.

As shown in FIG. **1**, the water-heating system **100** includes a water heater **105**, an outdoor unit (ODU) **110**, a water-heating cabinet **115**, a first refrigerant line **120**, a second refrigerant line **125**, a first water line **130**, a second water line **135**, and a sensor circuit **140**. The water heater **105** includes a water reservoir **180**, a heating element **185**, a tank drain valve **150**, and a pressure relief valve **155**. The water-heating cabinet **115** includes a control board **160**, a refrigerant-water heat exchanger **165**, and a recirculating water pump **170**.

The water heater **105** operates to heat water for use inside a building, e.g., in faucets, showers, washing machines, dishwashers, machinery, etc. The water heater **105** can also be referred to as a hot water tank or a boiler. When in domestic use, the water heater **105** will generally heat potable water suitable for individual use by the residents of the building. However, in some embodiments the water heater **105** may be an industrial water heater that heats non-potable water for industrial uses.

In the disclosed embodiments, the water heater **105** is a storage water heater that maintains a quantity of water in the water reservoir **180** at a relatively high temperature (i.e., above ambient temperature) available for immediate use. In operation, the water heater **105** continually ort periodically monitors the temperature of water in its water reservoir **180**. When the temperature of the water in the water reservoir **180** drops below a threshold value, the water heater **105** activates its heating element **185** to heat the water such that the water temperature rises above the threshold temperature.

Once the water in the water reservoir **180** rises above the threshold temperature, water heater **105** will deactivate the heating element **185** until such a time as the water temperature in the water reservoir **180** again falls below the threshold temperature.

The water reservoir **180** is a part of the water heater **105** that contains water for heating. Typically, it makes up the bulk of the water heater **105**. The water reservoir **180** will have an inlet pipe (not shown) that receives unheated water from a water supply (e.g., the building's water pipes), and an outlet pipe (not shown) that provides heated water to locations in the building (e.g., bathrooms, kitchens, etc.). In addition, the water reservoir **180** can be accessed by the tank drain valve **150** and the pressure relief valve **155**.

The heating element **185** is a device that is configured to heat the water in the water reservoir **180**. There are multiple possible implementations of the heating element **185** including: an electric heater, a natural gas heater, an oil heater, a coal heater, a kerosene heater, and a gasoline heater. However, this list is by way of example only. Any suitable device that heats water can be used as the heating element **185**.

The water heater **105** can be a conventional water heater used to heat water for use in a building without consulting any components outside the water heater **105**. However, the water heater **105** will also require connections that allow the water in its water reservoir **180** to flow out of the water reservoir **180** in the water heater **105** into the refrigerant-water heat exchanger **165** in the water-heating cabinet **115** and back from the refrigerant-water heat exchanger **165** into the water reservoir **180** in the water heater **105**. These connections can be pre-existing connections for access to the water reservoir **180**, e.g., the tank drain valve **150** or the pressure relief valve **155**. Alternatively, they can be connections added to a conventional water heater **105** to provide the necessary access. If an existing tank drain valve **150** and pressure relief valve **155** are used, then there would be no need to modify an existing water heater **105** to connect to the water-heating cabinet **115**. In this way, there would be no need for any significant increase in complexity, size, or cost of the water heater **105** as compared to a water heater **105** that operates independently of a water-heating cabinet **115**.

Absent the operation of the water-heating cabinet **115**, the water heater **105** is set to try and keep the water in its water reservoir **180** at a target water temperature. However, to keep the heating element from continually turning on, the water heater typically operates based on two temperature set points: a lower temperature set point (LSP) and an upper temperature set point (USP). The LSP represents the water temperature at or below which the water heater **105** will begin heating the water in its water reservoir **180**. The USP represents the maximum water temperature to which the water heater **105** will heat the water in its water reservoir **180**.

For example, consider a situation in which a water heater **105** has an LSP of 95° F. and a USP of 120° F. This would mean that the water heater **105** is programmed to try and keep the water temperature no hotter than 120° F. and no cooler than 95° F. When the water heater **105** determines that temperature of the water in the water heater **105** reaches 95° or lower, it will activate the heating element **185** to begin heating the water. Then, when it determines that the water temperature reaches 120° F. the water heater **105** will deactivate the heating element **185** until such a time as the water temperature again reaches 95° F. or lower. Thus, the water heater **105** doesn't actually maintain the water at its USP, but instead maintains it at a temperature between the LSP and the USP.

The outdoor unit **110** is an outdoor component of a conventional air-conditioning system. It can either include a heat pump or can operate as a heat pump, providing heating or cooling to an indoor space inside of a building using a refrigerant as a heat exchange mechanism. In a heating mode, the heat pump uses heat from an ambient source (e.g., outside air) to warm the refrigerant and thereby provide the heat required to heat the indoor space in a manner that would be understood by one skilled in the air-conditioning arts. In a cooling mode, the heat pump operates to exchange heat from the refrigerant to the ambient source (e.g., outside air) to cool the refrigerant and thereby provide the cooling required to cool the indoor space in a manner that would be understood by one skilled in the air-conditioning arts.

This outdoor unit **110** can be a conventional outdoor unit used in a conventional air-conditioning system. However, the outdoor unit **110** will require connections that allow the refrigerant in the outdoor unit **110** to flow out of the outdoor unit **110** into the refrigerant-water heat exchanger **165** and back from the refrigerant-water heat exchanger **165** into the outdoor unit **110**. These connections can be pre-existing connections for access to the refrigerant, e.g., refrigerant drainage access valves, or can involve modifications to a outdoor unit **110** to provide such access. Typically, providing access to the refrigerant can be easily made without significant increases in complexity, size, or cost of the outdoor unit **110**.

Although FIG. **1** discloses an outdoor air-conditioning unit **110** as a source of refrigerant to the refrigerant-water heat exchanger **165**, this is by way of example only. Alternate embodiments could obtain refrigerant for the refrigerant-water heat exchanger **165** from any other sources that warms a refrigerant using waste heat. For example, one alternate embodiment could replace the outdoor unit **110** with a power plant used to produce electric power (e.g., using coal, oil, natural gas, nuclear, etc.) that heats a refrigerant using its waste heat. Another alternate embodiment could replace the outdoor unit **110** with industrial machinery (e.g., an oil refinery, a steel mill, a glass factory, etc.) that heats a refrigerant using its waste heat. Yet another alternate embodiment could replace the outdoor unit with a collection of electronic components (e.g., a computer room or a server farm) that heats a refrigerant using its waste heat. Any suitable source of waste heat can be used in other embodiments.

The water-heating cabinet **115** serves as an intermediary between the water heater **105** and the outdoor unit **110**, allowing water from the water heater **105** to be heated by the refrigerant, which is heated by waste heat from the outdoor unit **110**.

The first refrigerant line **120** and the second refrigerant line **125** serve to connect the outdoor unit **110** to the refrigerant-water heat exchanger **165** and provide a path for refrigerant to pass from the outdoor unit **110** to the refrigerant-water heat exchanger **165** and from the refrigerant-water heat exchanger **165** to the outdoor unit **110**. As shown in the embodiment of FIG. **1**, refrigerant passes from the outdoor unit **110** to the refrigerant-water heat exchanger **165** via the first refrigerant line **120**, and refrigerant passes from the refrigerant-water heat exchanger **165** back to the outdoor unit **110** via the second refrigerant line **125**.

The first water line **130** and the second water line **135** serve to connect the water heater **105** to the refrigerant-water heat exchanger **165** and to provide a path for water to pass from the water heater **105** to the refrigerant-water heat exchanger **165** and from the refrigerant-water heat exchanger **165** to the water heater **105**. As shown in the embodiment of FIG. **1**, water passes from the water heater **105** to the refrigerant-water heat exchanger **165** via the first water line **130**, and water passes from the refrigerant-water heat exchanger **165** to the water heater via the second water line **135**.

In the embodiment of FIG. **1**, the first water line **130** is connected to the tank drain valve **150** and receives water from the water reservoir **180** in the water heater **105** via the tank drain valve **150**. Likewise, the second water line **135** is connected to the pressure relief valve **155** and provides water to the water reservoir **180** in the water heater **105** via the pressure relief valve **155**.

The sensor circuit **140** includes one or more sensors that can be used to monitor the operation of the water heater **105**. Specifically, current If the heating element **185** is a different kind of heater, the heating element sensor would be configured accordingly such that it properly indicated when the heating element **185** was activated.

In some embodiments the sensor circuit **140** will be an integral part of the water heater **105**. For example, the water heater could be designed to operate with a water-heating cabinet **115** from the start. In other embodiments the sensor circuit **140** will be a device separate from the water heater **105** that attaches to the water heater **105**. For example, the sensor circuit **140** could be an add-on that allows a water-heating cabinet **115** to be connected to an existing water heater **105** without the need to significantly modify the water heater **105**.

The tank drain valve **150** is a valve that allows water to be drained from the water reservoir **180** in the water heater **105**. Typically, the tank drain valve **150** is provided at the bottom of the water heater **105** so that gravity will allow the water to drain from the water reservoir **180** in the water heater **105** without the need for a pump. For similar reasons the first water line **130** is connected to the tank drain valve **150** so that water can be more easily provided from the water heater **105** to the refrigerant-water heat exchanger **165**. Although the recirculating water pump **170** will operate to move water from the water heater **105** through the refrigerant-water heat exchanger **165**, and back to the water heater **105**, gravity and water pressure at the bottom of the water heater **105** will mean that the recirculating water pump **170** will not have to work as hard to pump the water. Furthermore, the connection of the first water line **130** to the tank drain valve **150** means that if the water heater **105** is not full of water, the first water line **130** will still be able to draw water from the water reservoir **180**.

In some embodiments the first water line **130** may be connected to the tank drain valve **150** using a three-way connector in which one of the openings performs the function of a conventional tank drain valve **150**. In this way, the tank drain valve **150** can still be used to drain water from the water reservoir **180** in the water heater **105** when desired.

The pressure relief valve **155** is a valve in the water heater **105** that allows water or steam to escape from the water reservoir **180** of the water heater **105** to prevent an undesirable pressure buildup in the water reservoir **180** of the water heater **105**. It is generally designed to open temporarily and discharge short spurts of water or steam when the temperature of the water in the water heater **105** exceeds a maximum allowable temperature (e.g., 200-220° F.) or when the pressure in the water reservoir **180** of the water heater **105** exceeds a maximum allowable pressure (e.g., 140-160 psi).

Typically, a pressure relief valve **155** in a water heater **105** is provided near the top of the water reservoir **180** in the water heater **105** so that water or steam can be released to reduce the pressure in the water reservoir **180** without causing additional water in the water reservoir **180** to drain out. The second water line **135** is connected to the pressure relief valve so that water can be returned to the water reservoir **180** from the refrigerant-water heat exchanger **165** more easily.

In some embodiments the second water line **135** may be connected to the pressure relief valve **155** using a three-way connector in which one of the openings performs the function of a conventional pressure relief valve **155**. In this way, the pressure relief valve **155** can still be used to release water/steam from the water reservoir **180** in the water heater **105** when necessary.

By connecting the first and second water lines **130**, **135** to the tank drain valve **150** and the pressure relief valve **155**, respectively, the water-heating cabinet **115** can be connected to an existing water heater **105** without the need for significant modification of the water heater **105**. However, alternate embodiments could provide one or two additional valves on the water heater **105** that are dedicated to connecting the first and/or second water lines **130**, **135** to the water heater **105**.

The control board **160** includes a controller that serves to control the operation of the components of the water-heating cabinet **115** based, in part, on sensor data received from the sensor circuit **140**, operational signals received from the outdoor unit **110**, and its own operating parameters. For example, the control board **160** may receive sensor data from the sensor circuit **140** and operational signals from the outdoor unit **110** and use that sensor data and operational signals to determine when to control the recirculating water pump **170** to pump water from the water heater **105** to the refrigerant-water heat exchanger **165**. In some embodiments the control board **160** may also provide information to the outdoor unit **110**.

In some embodiments the control board **160** can include a microprocessor, an application-specific integrated circuit (ASIC), or another suitable circuit for controlling operation of the components of the water-heating cabinet **115**.

The refrigerant-water heat exchanger **165** receives refrigerant from the outdoor unit **110** (via the first refrigerant line **120**) and water from the water heater **105** (via the first water line **130**) and facilitates the transfer of heat from the refrigerant to the water. It then provides the cooled refrigerant back to the outdoor unit **110** (via the second refrigerant line **125**) and provides the heated water back to the water heater **105** (via the second water line **135**).

In the disclosed embodiment of FIG. **1**, the refrigerant-water heat exchanger **165** includes a refrigerant pathway and a water pathway. The refrigerant pathway may be a pipe coil that is connected to the first and second refrigerant lines **120**, **125** and allows the refrigerant to flow through it. Likewise, the water pathway may be a pipe coil that is connected to the first and second water lines **130**, **135** and allows the water to flow through it. The water pathway may also be called a hydronic coil. The refrigerant pathway and the water pathway are typically formed proximate to each other such that heat can easily transfer from the refrigerant in the refrigerant pathway to the water in the water pathway.

Alternate embodiments can employ any suitable structure for the refrigerant pathway and the water pathway that facilitates the passage of refrigerant and hot water and the transfer of heat from the refrigerant to the water. For example, the refrigerant pathway and water pathway could be formed to be parallel to each other, intertwined with each other, etc.

The water-heating cabinet **115** can be located proximate to the water heater **105**, proximate to the outdoor unit **110**, or at any suitable location between the water heater **105** and the outdoor unit **110** as desired.

In the disclosed embodiments the water-heating cabinet **115** is formed outside of both the water heater **105** and the outdoor unit **110** so that the water-heating cabinet **115** can be used with a conventional water heater **105** and a conventional outdoor unit **110** without having to make significant modifications to either unit. However, alternate embodiments can include the water-heating cabinet **115** as an integral part of either the water heater **105** or the outdoor unit **110**.

The recirculating water pump **170** operates to pump water from the water heater **105** through the first water line **130** to the hot water pathway in the refrigerant-water heat exchanger **165** and then through the second water line **135** back to the water heater **105** when heat is to be exchanged between the refrigerant and the water. In the disclosed embodiment the recirculating water pump **170** is located on the second water line **135** between the refrigerant-water heat exchanger **165** and the pressure relief valve **155**. However, this is by way of example only. In alternate embodiments the recirculating water pump **170** may be located anywhere between the water heater **105** and the refrigerant-water heat exchanger **165** where it can pump the water from the water heater **105** to the refrigerant-water heat exchanger **165**.

In various embodiments the recirculating water pump **170** could be a centrifugal water pump or a positive displacement water pump, depending upon the requirements of water pumping for the system.

Although not shown, the water heating system **100** will also have a pump of some kind (not shown) to move the refrigerant from the outdoor unit **110** through the first refrigerant line **120**, the refrigerant pathway in the refrigerant-water heat exchanger **165** and the second refrigerant line **125**. This pump may be in the outdoor unit **110**, between the outdoor unit **110** and the water-heating cabinet **115**, or in the water-heating cabinet **115**.

By running the recirculating water pump **170**, water is taken from the water heater **105**, passes through the first water line **130** to the hot water pathway in the refrigerant-water heat exchanger **165**, absorbs heat from a refrigerant supplied by the outdoor unit **110**, then passes through the second water line **135** back to the water heater **105**. The system **100** can therefore circulate water from the water heater **105** to the refrigerant-water heat exchanger **165**, thereby heating the water by heat transfer with the hot refrigerant without the need to operate the heating element **185** in the water heater **105**.

Sensor Circuit

FIG. **2** is a block diagram of the sensor circuit **140** of FIG. **1** according to disclosed embodiments. As shown in FIG. **2**, the sensor circuit **140** includes a temperature sensor **210**, a heating element sensor **220**, and a communication circuit **230**.

The temperature sensor **210** is configured to measure the temperature of the water in the water reservoir **180** of the water heater **105**. In some embodiments the temperature sensor **210** could be a separate sensor that attaches to the water heater **105** to measure the temperature of the water in the water reservoir **180**. In other embodiments the temperature sensor **210** could be a circuit that operates to read a temperature of the water in the water reservoir **180** detected from a different temperature sensor integral to the water heater **105**. Regardless, the operation of the temperature sensor **210** will not interfere with the normal operation of the water heater **105**.

The heating element sensor **220** is configured to measure a parameter of the heating element **185** that is indicative of whether the heating element **185** is on or off. For example, if the heating element **185** is an electric heating element, the measured parameter could be the current used by the electric heating element in the water heater **105** or by the water heater **105** in general. This current serves as an indicator as to whether the heating element is on or off. If the detected current used is below a current threshold, the control board **160** will determine that the electric heating element is off; and if the detected current used is above the current threshold, the control board **160** will determine that the electric heating element is on.

In alternate embodiments in which different types of heating elements **185** are used, the specific parameters of the heating element sensor **220** will vary, though the data it generates will always be indicative of whether the heating element **185** is on or off. For example, if a natural gas heating element, an oil heating element, or a coal heating element is used, the heating element sensor **220** could be a second temperature sensor that determines the temperature of a heating portion of the heating element **185**. The temperature of the heating portion of the heating element could be considered an indicator that the natural gas/oil/coal heating element was turned on. If the detected temperature of the heating element was above a heating element temperature threshold, then the heating element **185** would be determined to be on; and if the detected temperature of the heating element was below the heating element temperature threshold, then the heating element **185** would be determined to be off.

Alternatively, if a natural gas or oil heating element is used, the heating element sensor **220** could be a gas/oil flow sensor to determine if natural gas is flowing to the heating element **185** from an oil/gas source. The flow of oil/natural gas could be considered an indicator that the heating element **185** was turned on. Other sensors could be used in other embodiments to detect a parameter indicative of the operation of the heating element **185**.

The communication circuit **230** is configured to receive temperature data from the temperature sensor and current data from the current sensor **220** and provide that temperature data and current data to the control board **160**. The communication circuit **230** could be a wired communication circuit using a wired protocol (e.g., Ethernet, RS-232, RS-485, etc.) or it could be a wireless communication circuit using a wireless protocol (e.g., WiFi, LiFi, Bluetooth, Zigbee, etc.).

Control Board

FIG. **3** is a block diagram of the control board **160** of FIG. **1** according to disclosed embodiments. As shown in FIG. **3**, the control board **160** includes a controller **310**, a sensor communication circuit **320**, and an ODU communication circuit **330**.

The controller **310** is a circuit configured to receive data form the outdoor unit **110** and the sensor circuit **140** and to use that received data to control the operation of the components of the water-heating cabinet **115**, primarily the recirculating water pump **170**. The controller **310** can include a microprocessor, an application-specific integrated circuit (ASIC), or any other suitable circuit for controlling operation of the components of the water-heating cabinet **115**. Although not shown, the controller **310** may also include a memory (volatile, non-volatile, or both) to store information and operating programs.

The sensor communication circuit **320** is configured to receive temperature data and current data from the communication circuit **230** in the sensor circuit **140** and to provide that temperature data and current data to the controller **310**. The sensor communication circuit **320** could be a wired communication circuit using a wired protocol (e.g., Ethernet, RS-232, RS-485, etc.) or it could be a wireless communication circuit using a wireless protocol (e.g., WiFi, LiFi, Bluetooth, Zigbee, etc.).

The ODU communication circuit **330** is configured to receive outdoor unit operation data from the outdoor unit

110 and provide that operation data to the controller 310. In some embodiments the ODU communication circuit 330 is also configured to receive outdoor unit operation data from the controller 310 and provide that operation data to the outdoor unit 110. The ODU communication circuit 330 could be a wired communication circuit using a wired protocol (e.g., Ethernet, RS-232, RS-485, etc.) or it could be a wireless communication circuit using a wireless protocol (e.g., WiFi, LiFi, Bluetooth, Zigbee, etc.).

By monitoring the temperature of the water in the water reservoir 180 of the water heater 105 and the availability of hot refrigerant from the outdoor unit 110, the controller 310 in the control board 160 of the water-heating cabinet 115 can operate the water-heating cabinet 115 to draw water from the water heater 105 prior to when the water heater 105 would turn on its heating element 185 and instead heat the water via heat exchange with the hot refrigerant when it is available. In this way, the waste heat from the outdoor unit 110 can be used to warm the water in the water heater 105, saving resources (electricity, natural gas, oil, etc.) that would otherwise be consumed by the heating element 185.

Furthermore, the water-heating cabinet 115 can achieve this operation without the need to alter the operation of the water heater 105. In other words, it can be retrofitted to any existing water heater 105 without the need to change the operation or configuration of the water heater 105. In addition, the water heater 105 can still operate in its normal operation mode so that when the water-heating cabinet cannot provide heat through a heat-exchange process for any reason (e.g., hot refrigerant is not available, the water-heating cabinet 115 malfunctions, etc.), the water heater 105 can act as it normally would, keeping the water in the water heater 105 at a desired temperature using the heating element 185.

Method of Operating a Water-Heating System

FIG. 4 is a flow chart describing the operation 400 of a water-heating system using waste heat according to disclosed embodiments.

As shown in FIG. 4, the operation 400 begins by determining a lower temperature set point (LSP) for a water heater 105 (405), i.e., the temperature at or below which the water heater 105 turns on a heating element 185 to heat the water in a water reservoir 180 in the water heater 105. This can be achieved by monitoring normal operation of the water heater 105 and determining the temperature of the water at which the water heater 105 activates the heating element 185. This temperature represents the LSP for the water heater 105.

The system then determines an upper temperature set point (USP) for the water heater 105 (410), i.e., a temperature at or above which the water heater 105 turns off the heating element 185 after it has activated the heating element 185 to heat the water in the water reservoir 180. This can be achieved by monitoring normal operation of the water heater 105 and determining the temperature of the water at which the water heater 105 deactivates the heating element 185 after it is first activated to heat the water in the water reservoir 180. This temperature represents the USP for the water heater 105.

In this way, by monitoring the normal operation of the water heater 105 without any interference from a water-heating cabinet 115, the system can determine at what water temperature the water heater 105 is set to begin heating water (i.e., its LSP) and at what water temperature the water heater 105 is set to stop heating water (i.e., its USP).

Once the system has determined the LSP and the USP of its associated water heater 105 (405, 410), it will begin measuring the current water temperature T_W of the water in the water heater 105 (415) and determining whether the current water temperature T_W is below the LSP plus a temperature differential Δ_{TEMP}. (i.e., is T_W<LSP+Δ_{TEMP}) (420).

If the current water temperature T_W is not below the LSP plus the temperature differential Δ_{TEMP}, then the system continues to periodically or continually monitor the current water temperature T_W, (415) to determine if it is below the LSP plus a temperature differential Δ_{TEMP} (420), but otherwise takes no further action. Under these circumstances, the water in the water heater 105 is sufficiently hot that it does not require further heating.

If, however, the current water temperature T_W is below the LSP plus the temperature differential Δ_{TEMP}, then the water in the water heater 105 requires heating. The system therefore determines whether it can heat the water using waste heat from a refrigerant source (e.g., an outdoor unit of an air-conditioner) prior to the current water temperature T_W falling low enough that the water heater 105 will activate its heating element 185. The system can act before the water heater 105 activates its heating element 185 because the system is making its determination at a temperature of (LSP+Δ_{TEMP}), which is higher than the LSP alone, while the water heater 105 makes its determination to activate the heating element 185 at the LSP alone. In other words, the system is set to make its decision at a higher water temperature that occurs immediately before the water heater 105 would have activated its heating element 185.

In some embodiments the temperature differential Δ_{TEMP} can be constant. In other embodiments the temperature differential Δ_{TEMP} can vary depending upon system parameters of the water heater 105. For example, the temperature differential Δ_{TEMP} can vary based on the rate of change of the water temperature T_W in the water heater. The temperature differential Δ_{TEMP} may be higher when the rate of change of the water temperature T_W is high and lower when the rate of change of the water temperature T_W is low.

The rate of change of the water temperature T_W could be comparatively high when the residents of the building in which the water heater 105 is located are using a lot of hot water. In this case, the water-heating system may want a comparatively greater lead time to heat the water from the water heater 105 to prevent it from dropping below the LSP and triggering the water heater 105 to activate its heating element 185. As a result, the water-heating system might set the temperature differential Δ_{TEMP} to a comparatively higher level so that the system can start heating the water using the refrigerant earlier than it would with a comparatively lower value for the temperature differential Δ_{TEMP}.

Likewise, the rate of change of the water temperature T_W could be comparatively low when the residents of the building in which the water heater 105 is located are not using much or any hot water. If they are currently using no hot water, the drop in temperature of the water in the water heater may be solely because of heat leaking into the atmosphere from the water heater 105. In this case, the water-heating system may not need much of a lead time to heat the water from the water heater 105 since the leakage of heat to the atmosphere is typically small and slow. As a result, the water-heating system might set the temperature differential Δ_{TEMP} to a comparatively lower level so that the system will start heating the water using the refrigerant when the current water temperature T_W in the water heater 105 is very close to the LSP.

In still other embodiments the temperature differential Δ_{TEMP} can vary depending upon the rate of outflow of the water from the water heater **105**. The temperature differential Δ_{TEMP} may be higher when water is being drawn from the water heater **105** at a comparatively high rate and lower when water is being drawn from the water heater **105** at a comparatively lower rate or not at all. As water flows out of the water heater **105** it will have to be replaced by water at an ambient temperature, which will tend to lower the current temperature of the water T_W. If no water is being drawn out of the water heater **105**, it is only losing heat based on what leaks out to the ambient atmosphere.

In some embodiments the temperature differential Δ_{TEMP}; can vary between about 1.5° F. and 3° F., though this is by way of example only. Different embodiments can use whatever temperature differential Δ_{TEMP} is most suited to the needs of the system.

After determining that the current water temperature T_W in the water heater **105** is below the LSP plus a temperature differential Δ_{TEMP}, the system next determines whether heating is available from the refrigerant source (**425**). It may be that in some refrigerant sources there will sometimes be waste heat available and will sometimes not be waste heat available. For example, if the refrigerant source is an outdoor unit of an air-conditioner, it will have waste heat available if it is in a cooling mode, but not if it is in a heating mode. A determination that heating is available requires that the refrigerant source have sufficient waste heat that the temperature of the refrigerant that can be provided will be greater than or equal to the USP. In other words, the refrigerant must be hot enough that it can transfer some of its heat to the water.

If the system determines that there is no waste heat available, it proceeds to heat the water, as necessary, using the heating element **185** in the water heater **180** (**430**). Essentially, the system controller will do nothing, allowing the current water temperature T_W to fall below the LSP, at which point the water heater **105** will activate its heating element to heat the water in the water heater **105**.

Once the water heater **105** activates its heating element **185**, the system will then measure the current water temperature T_W, sending the value of the current water temperature T_W to a controller (**430**), and determine whether the current water temperature T_W rises above the USP (**440**). In other words, the system will allow the water heater **105** to operate normally, heating the water using its heating element **185**.

If the current water temperature T_W has not yet risen to be equal to or greater than the USP (**440**), then the system will again check whether heating is available from the refrigerant source (**425**) and proceed accordingly.

If, however, the current water temperature T_W rises to be equal to or greater than the USP (**440**), the water heater **105** will deactivate the heating element **185** and return to measuring the current water temperature T_W (**415**) and determining whether it is below the LSP plus a temperature differential Δ_{TEMP} (**420**).

In this way, if heating is not available from the refrigerant source (**425**), the water heater **105** will operate exactly as it would have if the water-heating system not been in place. The water in the water reservoir **180** in the water heater **105** will be heated by the heating element **185** and the occupant of the building in which the water heater **105** is located will get the hot water they desire.

If there is heating available from the refrigerant source, however (**425**), the system will proceed to use the hot refrigerant to heat the water in the water heater **105**. Furthermore, because this operation was triggered by the current water temperature T_W falling below the LSP plus the temperature differential Δ_{TEMP}, it will occur before the water heater **105** has a chance to activate its heating element **185**, which occurs when the current water temperature T_W falls below the LSP.

The system sends heated refrigerant from the refrigerant source to a refrigerant side of a refrigerant-water heat exchanger **165** (**445**) and sends water from the water heater **105** to a water side of the refrigerant-water heat exchanger **165** (**450**). Heat is then exchanged between the hot refrigerant and the relatively cooler water (**455**), causing the refrigerant to become cooler and the water to become hotter.

As this is occurring, the system continues to periodically or continually measure the current water temperature T_W, sending the value of the current water temperature T_W to a controller (**460**), and determine whether the current water temperature T_W rises above the USP (**440**). In other words, the system will continue to heat the water using the hot refrigerant rather than the heating element **185**.

If the current water temperature T_W has not yet risen to be equal to or greater than the USP (**440**), then the system will again check whether heating is available from the refrigerant source (**425**) and proceed accordingly. If there continues to be heating available from the refrigerant source, the water heating system will continue to use the hot refrigerant to heat the water.

If, however, the current water temperature T_W rises to equal to or greater than the USP (**440**), the water heater **105** system will stop sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger **165** (**465**) and will stop sending water from the water heater **105** to the refrigerant-water heat exchanger (**470**). It will then return to measuring the current water temperature T_W (**415**) and determining whether it is below the LSP plus a temperature differential Δ_{TEMP} (**420**). In this situation the system will have fully heated the water in the water heater **105** to the USP, allowing the system to wait until the water has again dropped below the LSP plus the temperature differential Δ_{TEMP} until action must again be taken.

In this way, if heating is not available from the refrigerant source (**425**), the water heater **105** will operate exactly as it would have if the water-heating system not been in place. The water in the water reservoir **180** in the water heater **105** will be heated and the occupant of the building in which the water heater **105** is located will get the hot water they desire. However, if heating is available, the system will begin heating water from the water heater **105** using the hot refrigerant just before the water heater **105** would have activated its heating unit. In other words, the system can prevent the water heater **105** from expending the resources required by the heating element **185** (e.g., electric power, natural gas, oil, etc.) and can instead heat the water using the waste heat from the refrigerant source. This can save those resources and thereby save the building owner or operator money.

Determining LSP and USP

To operate properly, a water heater **105** will either have a value for both a lower temperature set point (LSP) and an upper temperature set point (USP) known to a local water heater controller or will have a value for one of the LSP and the USP known to the local water heater controller and will have a way off deriving the value of the other of the LSP and the USP. For example, in one embodiment the water heater **105** could have a set value for the USP and a rule to set the LSP to be 20% or 25% lower than the USP. In another embodiment the water heater **105** could have a set value for the USP and a standard value for the LSP (e.g., 90° F.). In yet another embodiment the water heater **105** could have a temperature value set from which both the LSP and the USP are derived. Other ways of determining the LSP and USP are possible.

However, a water heater **105** may not have any mechanism provided for communicating its associated LSP and USP with a component outside of the water heater **105**. If an external controller is to coordinate an exchange of heat between a refrigerant from a refrigerant source and water in such a water heater **105**, it would therefore be useful to have a way of determining the values for the LSP and USP for the water heater **105** without requiring that the water heater **105** be modified to provide that information.

FIG. **5** is a flow chart describing the operation of determining an LSP for a water heater **105** (**405**) in FIG. **4** according to disclosed embodiments. This operation can be performed by a system controller separate from the water heater **105** without any action being taken on the part of the water heater **105**.

As shown in FIG. **5**, this operation begins at a point when a heating element **185** in the water heater **105** is not activated (**510**), i.e., the water heater **105** is not currently heating the water it contains.

The system then monitors the heating element **185** to determine whether it is activated (**520**). It can use a detector such as the heating element detector **220** described above or any suitable detector. If the heating element **185** is not activated, then the system continues monitoring the heating element **185**. If it is activated, then the system determines the current water temperature T_W in the water heater **105** at the time when the heating element was activated (**530**).

The system then sets the LSP to be equal to the current water temperature T_W in the water heater **105** at the time when the heating element was activated (**540**).

In other words, the system monitors the temperature of the water in the water heater **105** when its heating element **185** is turned off until it reaches a point when the heating element **185** turns on. Since the water heater **105** is configured to turn the heating element **185** on when its water temperature reaches the LSP, the water temperature T_W when the water heater **105** turns on the heating element **185** will correspond to the LSP for the water heater **105** stored in a water heater controller.

In this way, the system can determine the LSP for the water heater **105** simply by observation without the water heater **105** having to provide any information to a system controller. Thus, if an embodiment of a water heating system includes a water heater **105** without the capability to externally communicate its LSP, a system controller external to the water heater **105** can determine the LSP of the water heater **105** without requiring any modification to the water heater **105**.

FIG. **6** is a flow chart describing the operation of determining a USP for a water heater **105** (**410**) in FIG. **4** according to disclosed embodiments. This operation can be performed by a system controller separate from the water heater **105** without any action being taken on the part of the water heater **105**.

As shown in FIG. **6**, this operation begins at a point when a heating element **185** in the water heater **105** is activated (**610**), i.e., the water heater **105** is currently heating the water it contains.

The system then monitors the heating element **185** to determine whether it is activated (**620**). This could use a heating element detector **220** as described above, or any suitable detector. If the heating element is activated, then the system continues monitoring the heating element **185**. If it is not activated, then the system determines the current water temperature T_W in the water heater **105** at the time when the heating element was deactivated (**630**).

The system then sets the USP to be equal to the current water temperature T_W in the water heater **105** at the time when the heating element was deactivated (**640**).

In other words, the system monitors the temperature of the water in the water heater **105** when its heating element **185** is turned on until it reaches a point when the heating element **185** turns off. Since the water heater **105** is configured to turn the heating element **185** off when its water temperature reaches the USP, the water temperature T_W when the water heater **105** turns off the heating element **185** will correspond to the USP for the water heater **105** stored in a water heater controller.

In this way, the system can determine the USP for the water heater **105** simply by observation without the water heater **105** having to provide any information to a system controller. Thus, if an embodiment of a water heating system includes a water heater **105** without the capability to externally communicate its USP, a system controller external to the water heater **105** can determine the USP of the water heater **105** without requiring any modification to the water heater **105**.

Determining Whether Heating Elements are Activated

Generally, the heating element **185** in a water heater **105** is the component that consumes the most energy. As a result, when an electric heating element is used and the heating element **185** is activated, the current provided to the water heater **105** will increase significantly. A water-heating system with an electric heating element therefore uses the current supplied to the water heater **105** as an indicator as to whether the heating element **185** is activated. If the current is above a current threshold then the heating element **185** is determined to be activated; and if the current is below the current threshold then the heating element **185** is determined to not be activated. The current threshold is selected such that it differentiates between the current used by the water heater **105** when the heating element **185** is not activated and the current used by the water heater **105** when the heating element **185** is activated.

FIG. **7** is a flow chart describing the operation **520** of determining whether a heating element **185** in a water heater **105** is activated in FIGS. **5** and **6** according to disclosed embodiments. Specifically, FIG. **7** show an embodiment in which the heating element **185** is an electric heater.

As shown in FIG. **7**, the operation **520** begins by measuring an electric current I_{HE} being provided to the water heater **105** (**710**).

The system then compares the measured electric current I_{HE} with a threshold current I_{TH} to determine whether the measured electric current L_{IE} is greater than the threshold current I_{TH} (**720**).

If the electric current I_{HE} is above the threshold current I_{TH}, then the system determines that the heating element **185** is activated (**730**). If the electric current I_{HE} is below the threshold current I_{TH}, then the system determines that the heating element **185** is not activated (**740**).

In this way, the system can determine whether the heating element **185** is activated simply by observation without the water heater **105** having to provide any information to a system controller. Thus, if an embodiment of a water heating system includes a water heater **105** without the capability to externally communicate the status of its heating element **185**, a system controller external to the water heater **105** can determine whether the heating element **185** in the water heater **105** is activated without requiring any modification to the water heater **105**.

Although FIG. **7** discloses measuring the current flowing to the water heater **105** in general, alternate embodiments could measure the current being provided only to the heating element **185** in the water heater **105**.

Although FIG. **7** discloses a specific embodiment in which the heating element **185** in a water heater **105** is an electric heater, this is by way of example only. Alternate embodiments could use different operations to determine whether a heating element **185** is activated for other types of heating elements **185**.

For example, the system could measure the temperature of the heating element **185** and compare it to a threshold temperature, determining that the heating element **185** was activated if its temperature was above a temperature threshold and determining that the heating element **185** was not activated if its temperature was below the temperature threshold. Likewise, the system could monitor the flow of natural gas or oil in a natural gas or oil heating element, determining that the heating element **185** was activated if its gas or oil flow was above a flow threshold and determining that the heating element **185** was not activated if its gas or oil flow was below the flow threshold. Other operations to determine whether the heating element **185** is activated would also be possible.

Identifying when a Low Temperature Setpoint has Risen after being Set

Over time the LSP and USP in a hot water heater **105** may change, i.e., from LSP_{OLD} and USP_{OLD} to LSP_{NEW} and USP_{NEW}. For example, in a home environment a homeowner might decide to alter how hot they want the water in their water heater **105** to be. Likewise, in an industrial environment the required hot water temperature needs of an industrial process may change over time.

To maintain the efficiency of a water-heating process, it is desirable to take steps to make certain that a system controller is aware of any changes to the LSP and USP so that it can use current values for LSP and USP in operation. This will allow the system to begin and end its heat transfer process at the appropriate times, and avoids having the heating element **185** activated when hot refrigerant is available to heat the water in the water heater **105**.

For example, if the LSP of a water heater **105** is lowered (i.e., $LSP_{NEW}<LSP_{OLD}$), then a system using the old LSP (LSP_{OLD}) may act to heat the water in the water heater **105** sooner than it needs to, since the refrigerant-water heat transfer system will begin heating water through heat transfer with a refrigerant when the current water temperature falls below the (higher) LSP_{OLD} plus the temperature differential Δ_{TEMP} rather than when the water temperature falls below the (lower) LSP_{NEW} plus the temperature differential Δ_{TEMP}. This can be inefficient, but it still has the system implementing a heat transfer operation prior to the water heater **105** activating its heating element **185**.

However, if the LSP of the water heater **105** is raised, then the system may fail to act quickly enough to heat the water in the water heater **105** using heat transfer with a refrigerant before the water heater **105** activates its heating element **185**. This is because the water heater **105** will activate the heating element **185** when the current water temperature drops below the (higher) LSP_{NEW}, while the refrigerant-water heat transfer system will begin heating the water by heat transfer when the current water temperature drops below the (lower) LSP_{OLD} plus the temperature differential Δ_{TEMP}. The water heater **105** will activate the heating element **185** before the refrigerant-water heat transfer system begins heating water using a heat transfer operation if the (higher) LSP_{NEW} is greater than the (lower) LSP_{OLD} plus the temperature differential Δ_{TEMP}.

To keep operating efficiently, and to avoid the above problems, the water-heating system may continually or periodically monitor the hot water heater **105** to determine whether the LSP of the hot water heater **105** has been raised. FIG. **8** is a flow chart describing the operation **800** of identifying when a low temperature setpoint (LSP) has risen after being set.

As shown in FIG. **8**, the system begins by measuring the current water temperature T_W in the water heater **105** and sending the measured temperature T_W to a system controller (**805**) and by determining whether the current water temperature T_W is below the currently stored LSP plus a temperature differential Δ_{TEMP}. (i.e., is $T_W<LSP+\Delta_{TEMP}$) (**810**).

Operation **805** is comparable to operation **415** in the method **400** of FIG. **4**, and the description pertaining to operation **415** applies to the operation **805** of FIG. **8**. Operation **810** is comparable to operation **420** in the method **400** of FIG. **4**, and the description pertaining to operation **420** applies to the operation **810** of FIG. **8**.

If the current water temperature T_W is not below the LSP plus the temperature differential Δ_{TEMP}, then the system continues to monitor the current water temperature T_W, (**805**) to determine if it is below the LSP plus a temperature differential Δ_{TEMP} (**810**), but otherwise takes no further action. Under these circumstances, the water in the water heater **105** is sufficiently hot that it does not require further heating.

If, however, the current water temperature T_W is below the LSP plus the temperature differential Δ_{TEMP}, then the system determines whether the heating element **185** in the water heater **105** is already activated (**820**).

If the heating element **185** is not already activated, then the system will then proceed to exchange heat between heated refrigerant and water in a water-heating operation as described above (**830**). One way of achieving this is through operations **445-470** described with respect to FIG. **4**. Once this heat exchange operation is complete, the system returns to monitoring the current water temperature T_W, (**805**) to determine if it is below the LSP plus the temperature differential Δ_{TEMP} (**810**).

If, however, the heating element **185** in the water heater **105** is already activated when the system determines that the current water temperature T_W is below the LSP plus the temperature differential Δ_{TEMP}, it is likely that the LSP for the water heater **105** has been raised. This would cause the hot water heater **105** to activate the heating element **185** at a new LSP that is higher than a currently stored LSP known by the system plus the temperature differential Δ_{TEMP}.

In this case, the system will determine a new LSP for the hot water heater **105** (**840**) and determine a new USP for the hot water heater **105** (**850**). The operations of determining a new LSP for the hot water heater **105** (**840**) and determining a new USP for the hot water heater **105** (**850**) are comparable to the operations of determining a new LSP for the hot water heater **105** (**405**) and determining a new USP for the hot water heater **105** (**410**), respectfully, as described above with respect to FIGS. **4-6**. All the description regarding operations **405** and **410** apply to operations **840** and **850**, respectfully, including the descriptions of their operation with respect to FIGS. **5** and **6**. The operation of determining a new LSP for the hot water heater **105** (**840**) can be performed as described for the comparable operation of determining a new LSP for the hot water heater **105** (**405**) in FIG. **5**. Likewise, the operation of determining a new USP for the hot water heater **105** (**850**) can be performed as described for the comparable operation of determining a new USP for the hot water heater **105** (**410**) in FIG. **6**.

Once new values for the LSP and the USP have been determined, the system stores these values in a memory and returns to monitoring the current water temperature T_W, (**805**) to determine if it is below the new LSP plus the temperature differential Δ_{TEMP} (**810**).

In this way, the system can adjust its stored LSP value to the new, higher LSP used by the water heater **105** so that the system will continue to perform the heat-exchanging operation prior to the water heater **105** activating the heating element **185**.

This operation of monitoring the LSP of the water heater **105** to see if it has been raised can be performed coincident with the measurement process **410** described above with respect to the process of FIG. **4**. For example, the operation of determining whether the heating element **185** in the water heater **105** has been activated after determining that the current water temperature T_W is below the new LSP plus the temperature differential Δ_{TEMP} (**820**) can be inserted into the process described in FIG. **4** between operations **420** and **425**. In this case, the decision-making operation **820** will move processing to operations **840** and **850** if the system determines that the heating element **185** is activated and will move processing to operation **425** if the system determines that the heating element **185** is not activated.

Periodically Reevaluating the LSP and the USP

Since the LSP and USP in the water heater **105** may change from time-to-time, the system may also be configured to periodically check the values for the LSP and USP of the water heater **105** regardless of whether the temperature of the water in the water heater **105** has dropped below the LSP plus the temperature differential Δ_{TEMP}. In this way the system can maintain a current value for the LSP and USP independent of the operation of the water heater **105**.

FIG. **9** is a flow chart describing the operation **900** of periodically reevaluating the low temperature set point (LSP) and the upper temperature setpoint (USP) according to disclosed embodiments.

As shown in FIG. **9**, the operation **900** begins by setting a time counter C_{TIME} equal to zero (**910**). This time counter is used to determine when the system should update its values for LSP and USP.

The process continues by monitoring the time counter C_{TIME} and determining whether it is greater than or equal to a maximum time $TIME_{MAX}$ (**920**). The value for $TIME_{MAX}$ can be selected to be a maximum time that the system should go from the last time it determined the LSP and USP values for the water heater **105** to the next time it updates the values for the LSP and USP. Although not specifically shown in FIG. **9**, the system can be configured to reset the time counter C_{TIME} to zero any time the system determines a new value for the LSP and the USP of the water heater **105**.

If the time counter C_{TIME} is lower than the maximum time $TIME_{MAX}$, then the system will continue to engage in its normal temperature measuring and water-heating operation (**930**) as set forth, by way of example, in FIG. **4**.

Then the system will increment the value for the time counter C_{TIME} (**940**) and continue to evaluate whether the time counter C_{TIME} is greater than or equal to the maximum time $TIME_{MAX}$ (**920**). In this way the system will maintain its normal temperature measuring and water-heating operation from when the time counter C_{TIME} is reset to when it reaches the maximum time $TIME_{MAX}$.

If the time counter C_{TIME} is greater than or equal to the maximum time $TIME_{MAX}$, then the system will suspend normal operation (**950**), measure the current water temperature T_W in the water heater **105** (**960**), and begin monitoring the heating element **185** in the water heater **105** to see if it has been activated (**970**). In doing this, the system can determine at what water temperature T_W the water heater **105** activates the heating element **105**.

If the system determines that the water heater **105** has not been activated, it will again measure the current water temperature T_W in the water heater **105** (**960**) and continue monitoring the heating element **185** in the water heater **105** to see if it has been activated (**970**). It will continue these operations until the water heater **105** activates the heating element **185**.

If the system determines that the heating element **185** has been activated, it will then determine whether the current water temperature T_W is equal to the current LSP the system has stored (**970**). In other words, the system will determine whether the water heater **105** has activated the heating element **185** when the water temperature in the water heater **105** was equal to the currently stored value for the LSP.

The determination as to whether the current water temperature T_W is equal to or less than the current LSP can have a certain tolerance in various embodiments. In other words, the system can determine whether the current water temperature T_W is equal to or less than the current LSP based on a small tolerance value for T_W. This can be done to prevent the system from reevaluating the LSP and USP values based only on a tiny variance in the current water temperature T_W at which the water heater **105** activates the heating element **185**. The tolerance value should preferably be less than the temperature differential Δ_{TEMP}.

If the system determines that the current water temperature T_W is equal to the current LSP then it will reset the time counter C_{TIME} to zero (**910**), starting the process **900** all over again. In this situation the system will have determined that the currently stored LSP value remains valid since the LSP value is intended to represent the water temperature at which the water heater **105** activates the heating element **185**. As a result, there is no need for the system to redetermine the LSP value.

If the system determines that the current water temperature T_W is not equal to the current LSP then it will newly determine the LSP and USP for the water heater **105** (**983**, **986**) and then reset the time counter C_{TIME} to zero (**910**), starting the process **900** all over again. In this situation the system will have determined that the currently stored LSP value is no longer valid since the water heater **105** is activating the heating element **185** at a water temperature different from the LSP value stored by the heat transfer system.

The operations of determining a new LSP for the hot water heater **105** (**983**) and determining a new USP for the hot water heater **105** (**986**) are comparable to the operations of determining a new LSP for the hot water heater **105** (**405**) and determining a new USP for the hot water heater **105** (**410**), respectfully, as described above with respect to FIGS. **4-6**. All the description regarding operations **405** and **410** apply to operations **983** and **986**, respectfully, including the descriptions of their operation with respect to FIGS. **5** and **6**. The operation of determining a new LSP for the hot water heater **105** (**983**) can be performed as described for the comparable operation of determining a new LSP for the hot water heater **105** (**405**) in FIG. **5**. Likewise, the operation of determining a new USP for the hot water heater **105** (**986**) can be performed as described for the comparable operation of determining a new USP for the hot water heater **105** (**410**) in FIG. **6**.

The operation **900** of FIG. **9** shows that the system only actively determines whether the value for the stored LSP is correct, not the value for the stored USP. This is because when the stored LSP value is too low, the system may fail to initiate a heat transfer operation prior to the water heater **105** activating the heating element **185**, wasting system resources. No similar problem will occur if the stored USP value is incorrect.

However, alternate embodiments can modify this operation **900** to monitor whether the USP value is incorrect as well. For example, the system could also monitor the current water temperature T_W when the water heater **105** has deactivated the heating element **185** after having previously activated it. This deactivation water temperature is indicative of the USP value stored in the water heater **105**. It can be compared to the USP value stored by the heat transfer system to determine whether the stored USP value is correct. In such an embodiment, the system can redetermine values for LSP and USP when either the stored LSP value is determined to no longer correspond to the LSP value used by the water heater **105** or the stored USP value is determined to no longer correspond to the USP value used by the water heater **105**.

Although FIG. **9** discloses discrete operations for checking whether the time counter C_{TIME} is greater than the maximum time $TIME_{MAX}$ (**920**), engaging in the temperature measuring and water-heating operation (**930**), and incrementing the time counter CT (**940**), in some embodiments these operations can be performed using a timer and circuitry that monitors the value of the timer. The water-heating system can operate normally in parallel with the timer while the timer's value is below the maximum time $TIME_{MAX}$. Then, when the monitoring circuitry determines that the timer has reached the maximum time $TIME_{MAX}$, the system can suspend normal operation **950** and proceed with operations **950-970**, **405**, **410**, and **980** as shown in FIG. **9**. The system will then zero out the timer and start the process all over again.

Determining Whether a Refrigerant Source has Heated Refrigerant Available

For the heat transfer system to transfer heat from a refrigerant source to the water in the water heater **105** (operation **455** of FIG. **4**), the refrigerant source must first have sufficiently hot refrigerant available for heat transfer. FIG. **10** is a flow chart describing the operation **1000** of determining whether an outdoor unit of an air-conditioner has heated refrigerant available for heat transfer according to disclosed embodiments.

The operation **1000** of FIG. **10** assumes that water in the water heater **105** requires heating and that the system is therefore determining whether there is heated refrigerant available to heat the water. Therefore, it does not disclose an operation to determine whether the water in the water heater **105** requires heating.

As shown in FIG. **10**, the operation **1000** begins by determining the mode in which the outdoor unit of the air-conditioner is operating (**1010**). These modes include a cooling mode when the outdoor unit is providing relatively cool refrigerant to an interior portion of the air-conditioning system to cool air within a building, and a heating mode when the outdoor unit is providing relatively warm refrigerant to the interior portion of the air-conditioning system to warm air within the building.

When the outdoor unit is in the cooling mode, the refrigerant will absorb heat from inside the building and will have to dissipate that heat somewhere (typically into outside ambient air). As a result, the outdoor unit should have sufficiently hot refrigerant whose heat has to be dissipated before the refrigerant can be cooled sufficiently to be provided to the indoor component of the air-conditioning system. In contrast, when the outdoor unit is in the heating mode, the refrigerant will absorb heat from an external heat source. The heated refrigerant will be provided to the indoor portion of the air-conditioning system to warm the air inside the building. As a result, although the outdoor unit will have heated refrigerant, that heated refrigerant must be provided to the indoor portion of the air-conditioning system. It is not considered waste heat that can be used to heat water from the water heater **105**. Thus, it is only when the outdoor unit is in a cooling mode that it will have waste heat that needs to be dissipated in the form of a hot refrigerant.

The system therefore determines whether the outdoor unit is in a cooling mode or a heating mode (**1020**).

If the outdoor unit is in a heating mode, then it will not have waste heat to transfer to water from the water heater **105**. In this case, the system will allow the water heater **105** to engage in a temperature measuring and water heating operation without interference (**1030**). The water heater **105** will then use its heating element **185** to heat the water inside the water heater **105** as needed according to normal operation parameters.

If the outdoor unit is in a cooling mode, then it will have waste heat available to transfer to water from the water heater **105**. In this case, the system will proceed to transfer that waste heat to the water from the water heater **105**. Furthermore, since this waste heat does not consume resources (e.g., electric power, natural gas, oil, etc.) to generate, the system need not limit itself to only heating the water from the water heater **105** to the USP. The system can transfer as much waste heat as it can to the water from the water heater **105** without significantly increasing the cost of system operation.

Once it determines that the air-conditioning unit is in a cooling mode, the system therefore sends heated refrigerant from the outdoor unit **110** to a refrigerant-water heat exchanger **165** (**1040**), sends water from the water heater **105** to the refrigerant-water heat exchanger **165** (**1050**), and exchanges heat between the refrigerant and the water in the refrigerant-water heat exchanger **165** (**1060**). The system then again determines the mode of the air-conditioning unit (**1010**) and checks whether it is in a heating or cooling mode (**1020**) to make certain whether there is still waste heat to transfer to the water from the water heater **105**.

In this way, the outdoor unit **110** can provide hot refrigerant to heat the water in the water heater **105** when the outdoor unit **110** is in a cooling mode.

In alternate embodiments, the system can be configured to determine whether the water in the water heater **105** needs heating and then only provide refrigerant to transfer heat to the water from the water heater **105** when heating is required. For example, a resident of a building with a water heater **105** may determine that he USP in the water heater **105** is a maximum desired temperature for the water in the water heater **105**. This could happen, for example, if the building were a residential home and the resident was the parent of a small child. The parent might desire to limit the maximum temperature of the water in the water heater **105** to prevent their child from being scalded by hot water out of a faucet.

In such a case, the system could be configured such that when it determined that the air-conditioning unit was in a cooling mode (**1020**), it would then measure the water temperature T_W in the water heater **105** and determine whether the water temperature T_W in the water heater **105** was greater than or equal to the USP. If the water temperature T_W was determined to be under the USP then the water in the water heater **105** would be below the set maximum temperature and should be heated. The system would then send heated refrigerant from the outdoor unit to the water refrigerant heat exchanger (**1040**), send water from the water heater **105** to the water refrigerant heat exchanger (**1050**), and exchange heat between the heated refrigerant and the water (**1060**) to heat the water with the waste heat from the outdoor unit. If, however, the water temperature T_W was determined to be greater than or equal to the USP then the water temperature would be at or above its maximum temperature and the system would not perform operations **1040-1060**. Instead, it would return to determining the mode of the air-conditioning unit (**1010**) and proceeding accordingly.

Although FIG. **10** illustrates the operation of an embodiment in which a refrigerant source is an outdoor unit **110** of an air-conditioner, this is by way of example only. If a different refrigerant source is used, then a different operation may be required for determining whether the refrigerant source has sufficient hot refrigerant for heat transfer with water from the water heater **105**.

By using the disclosed operations, a water-heating system can use waste heat from a refrigerant source to heat the water in a water heater **105**. It does so by determining when the water heater **105** would otherwise heat the water it contains using a heating element **185** and then heating the water in the water heater **105** using heat exchange with the hot refrigerant at a temperature just above the temperature at which the water heater **105** would activate the heating element **185**. In this way the system can heat the water in the water heater **105** as needed using the waste heat as a heat source, while at the same time saving resources (e.g., electrical power, fuel, etc.) that the heating element **185** would otherwise consume in heating the water in the water heater **105** using the heating element **185**.

Furthermore, since the water-heating system acts just before the water heater **105** would otherwise have activated the heating element **185**, the operation should be effectively seamless, heating the water just as the water heater **105** would. As a result, the resident of a building that contains the water heater **105** should detect no difference in the operation of the water heater **105** regardless of how the water is heated.

The disclosed water-heating system and methods also allow the modification of a conventional water heater **105** to include the ability to heat the water in the water heater **105** using waste heat in the refrigerant without having to modify the water heater **105** in any significant way. A water-heating cabinet **115** can be connected between a refrigerant source and the water heater **105** using existing components in a conventional water heater **105**. The water-heating cabinet **115** can be connected to an existing tank drain valve **150** and pressure relief valve **155**, and a sensor circuit **140** can be attached to the outside of the water heater **105** with minimal effort.

In addition, the water-heating cabinet **115** doesn't actually interfere with the operation of the water heater **105**. It simply monitors the operation of the water heater **105** and heats the water in the water heater **105** just before the water heater **105** will heat it using the heating element **185**. As a result, if the water-heating cabinet **115** can't heat the water for any reason (e.g., it doesn't have sufficient heated refrigerant, it suffers a malfunction, etc.), the water heater **105** will operate as it would have without the presence of the water-heating cabinet **115** and the residents of the building to which the water heater **105** is attached will still have their water heated and will suffer no interruption in their supply of hot water.

Thus, the disclosed system and method can save resources (electrical power, fuel, etc.), which can save money for the operator of the water heater **105**. However, these savings will only occur when they are possible. When they are not, the water heater **105** will operate as it otherwise would have.

CONCLUSION

This disclosure is intended to explain how to fashion and use various embodiments in accordance with the invention rather than to limit the true, intended, and fair scope and spirit thereof. The foregoing description is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The embodiment(s) was chosen and described to provide the best illustration of the principles of the invention and its practical application, and to enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims, as may be amended during the pendency of this application for patent, and all equivalents thereof, when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled. The various circuits described above can be implemented in discrete circuits or integrated circuits, as desired by implementation.

What is claimed is:

1. A water-heating system, comprising:

a controller;

a refrigerant-water heat exchanger configured to exchange heat between refrigerant and water;

a temperature sensor configured to measure a current water temperature of water in a water heater and provide the current water temperature to the controller;

a first refrigerant pipe configured to pass the refrigerant from a refrigerant source to the refrigerant-water heat exchanger;

a second refrigerant pipe configured to pass the refrigerant from the refrigerant-water heat exchanger to the refrigerant source;

a first water pipe configured to pass the water from the water heater to the refrigerant-water heat exchanger;

a second water pipe configured to pass the water from the refrigerant-water heat exchanger to the water heater; and

a water pump configured to pump water from the water heater to the refrigerant-water heat exchanger via the first water pipe and from the refrigerant-water heat exchanger to the water heater via the second water pipe based on a pump control signal from the controller,

wherein

the first water pipe is connected to a tank drain valve on the water heater,

the second water pipe is connected to a pressure relief valve on the water heater, and

the controller is configured to

identify a lower temperature set point for the water in the water heater at which one or more heating elements in the water heater are set to heat the water,

determine when the current water temperature is below a threshold temperature but above the lower temperature set point, instruct the water pump to pump water to the refrigerant-water heat exchanger when the current water temperature is below the threshold temperature but above the lower temperature set point, and

instruct the refrigerant source to provide refrigerant to the refrigerant-water heat exchanger when the current water temperature is below the threshold temperature but above the lower temperature set point, and

the threshold temperature is a set temperature differential greater than the lower temperature set point.

2. The water-heating system of claim **1**, wherein the temperature sensor is attached to the water heater.

3. The water-heating system of claim **1**, further comprising:

a current sensor configured to measure an electric current value of an electric current provided to one or more heating elements in the water heater and provide the electric current value to the controller, and

the controller is further configured to

identify the lower temperature set point to be a first water temperature in the water heater when the electric current value first exceeds a current threshold,

identify an upper temperature set point to be a second water temperature in the water heater when the electric current value stops exceeding the current threshold,

instruct the water pump to stop pumping water to the refrigerant-water heat exchanger when the water in the water heater rises above the upper temperature set point, and

instruct the refrigerant source to stop providing refrigerant to the refrigerant-water heat exchanger when the water in the water heater rises above the upper temperature set point.

4. The water-heating system of claim **3**, wherein the one or more heating elements in the water heater are determined to be activated when the electric current value exceeds a current threshold and are determined to be deactivated when the electric current is below the current threshold.

5. The water-heating system of claim **1**, wherein the refrigerant source is an air-conditioner.

6. The water-heating system of claim **1**, wherein the controller is a microprocessor.

7. A method of heating water contained in a water heater, the method including:

determining a lower temperature set point that represents a temperature of water in the water heater below which one or more heating elements in the water heater activate to heat the water in the water heater; and

performing a first control, the first control including

measuring a water temperature in the water heater in the first control after determining the lower temperature set point;

determining that the water temperature measured in the first control is below a threshold water temperature but above the lower temperature set point;

sending heated refrigerant from a refrigerant source to a refrigerant-water heat exchanger after determining that the water temperature measured in the first control is below the threshold water temperature but above the lower temperature set point;

sending water from the water heater to the refrigerant-water heat exchanger after it is determined that the water temperature measured in the first control is below the threshold water temperature but above the lower temperature set point; and

exchanging heat between the refrigerant and the water from the water heater after sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger and sending water from the water heater to the refrigerant-water heat exchanger,

wherein

the threshold water temperature is a set temperature differential greater than the lower temperature set point.

8. The method of claim **7**, wherein

the set temperature differential varies based on a rate of change in water in the water heater.

9. The method of claim **7**, wherein the first control further comprises:

repeatedly measuring the water temperature measured in the first control and determining that the water temperature measured in the first control is above the threshold water temperature prior to determining that the water temperature measured in the first control is below the threshold water temperature but above the lower temperature set point.

10. The method of claim **7**, wherein the operation of determining the lower temperature set point includes performing a second control, the second control including:

determining whether one of the one or more heating elements in the water heater has been activated;

measuring a water temperature in the water heater in the second control in response to the one of the one or more heating elements in the water heater being activated; and

setting the lower temperature set point to be equal to the water temperature measured in the second control after it is determined that the one of the one or more heating elements in the water heater has been activated.

11. The method of claim **7**, wherein the operation of determining the lower temperature set point includes performing a third control, the third control including:

measuring an electric current provided to at least one of the one or more heating elements in the water heater in the third control;

measuring a water temperature in the water heater in the third control in response to measuring the electric current in the third control;

determining that the electric current measured in the third control is above a current threshold; and

setting the lower temperature set point to be equal to the water temperature measured in the third control after it is determined that the electric current measured in the third control is above the current threshold.

12. The method of claim **11**, wherein the third control further comprises:

repeatedly measuring the electric current, measuring the water temperature measured in the third control, and determining that the electric current measured in the third control is below the current threshold prior to determining that the electric current measured in the third control is above the current threshold.

13. The method of claim **7**, further comprising performing a fourth control, the fourth control including:

determining an upper temperature set point that represents a temperature of the water in the water heater above which the one or more heating elements are deactivated;

measuring a water temperature in the water heater in the fourth control after exchanging heat between the refrigerant and the water from the water heater;

determining that the water temperature measured in the fourth control is above the upper temperature set point after remeasuring the water temperature measured in the fourth control;

stopping sending heated refrigerant from the refrigerant source to the refrigerant-water heat exchanger after it is determined that the water temperature measured in the fourth control is above the upper temperature set point; and

stopping sending water from the water heater to the refrigerant-water heat exchanger after it is determined that the water temperature measured in the fourth control is above the upper temperature set point.

14. The method of claim **13**, wherein the fourth control further comprises:

repeatedly measuring the water temperature measured in the fourth control, and determining that the water temperature measured in the fourth control is below the upper temperature set point prior to determining that the water temperature measured in the fourth control is above the threshold water temperature.

15. The method of claim **13**, wherein the operation of determining the upper temperature set point includes:

exchanging heat between the refrigerant and the water from the water heater in the refrigerant-water heat exchanger; and

performing a third control, the third control including

measuring an electric current provided to at least one of the one or more heating elements in the water heater in the third control after exchanging heat between the refrigerant and the water from the water heater in the refrigerant-water heat exchanger;

measuring a water temperature in the water heater in the third control in response to measuring the electric current in the third control;

determining that the measured electric current measured in the third control is below a current threshold; and

setting the upper temperature set point to be equal to the water temperature measured in the third control after it is determined that the electric current measured in the third control is below the current threshold.

16. The method of claim **15**, wherein the third control further comprises:

repeatedly measuring the electric current in the third control, measuring the water temperature in the third control, and determining that the electric current measured in the third control is above the current threshold prior to determining that the electric current measured in the third control is below the current threshold.

17. The method of claim **7**, further comprising:

determining that heating is available for water in a water heater from the refrigerant source prior to measuring the water temperature in the first control.

18. The method of claim **17**, wherein

the refrigerant source is an air-conditioner, and

the operation of determining that heating is available from the refrigerant source includes

determining that the air-conditioner is in a cooling mode.

19. The method of claim **7**, further comprising:

comparing a current timer value to a threshold timer value prior to measuring the water temperature in the first control;

determining that the current timer value is greater than or equal to the threshold timer value based on the comparing of the current timer value to the threshold timer value; and

redetermining the lower temperature set point when the current timer value is greater than or equal to the threshold timer value prior to measuring the water temperature in the first control.

20. The method of claim **19**, wherein the operation of redetermining the lower temperature set point includes performing a fifth control, the fifth control including:

measuring an electric current provided to a heating element associated with the water heater in the fifth control;

measuring a water temperature in the water heater in the fifth control in response to measuring the electric current measured in the fifth control;

determining that the electric current measured in the fifth control is above the current threshold; and

setting the lower temperature set point to be equal to the water temperature measured in the fifth control after it is determined that the electric current measured in the fifth control is above the current threshold.

21. The method of claim **20**, further comprising:

repeatedly measuring the electric current in the fifth control, measuring the fifth water temperature in the fifth control, and determining that the electric current measured in the fifth control is below the current threshold prior to determining that the measured electric current measured in the fifth control is above the current threshold.

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